Low Impact Development Stormwater Control Cost Estimation Analysis

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Abbreviations

ASCE	American Society of Civil Engineers
ANSI	American National Standards Institute
ASQC	American Society for Quality Control
BMP	Best Management Practice
BMP-REALCOST	Best Management Practices Rational Estimation of Actual Likely Costs of Stormwater Treatment
CNT	Center for Neighborhood Technologies
ENR CCI	Engineering News Record Cost Comparison Index
EPA	U. S. Environmental Protection Agency
EWRI	Environmental and Water Resources Institute
EURV	Excess urban runoff volume
GIS	Geographic information systems
GSA	General Services Administration
HSG	Hydrologic soil group
IRR	Internal rate of return
LCC	Life cycle costing
LID	Low Impact Development
MPCA	Minnesota Pollution Control Agency
NCCES	North Carolina Cooperative Extension Service
NCHRP	National Cooperative Highway Research Program
NPV	Net present value
NSC	National Stormwater Calculator
NRMRL	National Risk Management Research Laboratory
O&M	Operating and maintenance
PWS	Performance Work Statement
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
SBPAT	Structural BMP Prioritization and Analysis Tool
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
TO	Task Order
UDFCD	Urban Drainage and Flood Control District
V	Volume (of storage)
WERF	Water Environment Research Foundation
WLC	Whole-Life Cost
WQCV	Water quality capture volume

Units of Measure

AF	Acre-ft
cfs	Cubic feet per second
ea	Each
ft^2	Square feet
ft^3	Cubic feet
gal	Gallon
hr	Hour
in	Inch(es)
LF	Linear feet
yr	Year

1. INTRODUCTION

1.1. Project Objectives

The Performance Work Statement (PWS) for Task Order (TO) 019 (PR-ORD-14-00308), Low Impact Development (LID) Stormwater Control Cost Estimation Analysis, states that the purpose of this TO is to develop cost data and estimation procedures for LID controls for eventual deployment within the U.S. Environmental Protection Agency's (EPA) National Stormwater Calculator (NSC). The integration of cost components of LID controls into the NSC is expected to improve NSC usefulness and to promote greater use of the calculator as a stormwater management and evaluation tool. The current NSC estimates runoff at a site based on soil conditions, landscape and land use information, topography, meteorology, existing and potential future climate conditions, and stormwater management controls (i.e., LID) that can be implemented on a site. The addition of cost estimation will allow planners and managers to evaluate LID controls based on comparison of project cost estimates and predicted LID control performance. This report includes a literature review of LID cost information; a critical review of pertinent cost estimation approaches with a recommended cost estimation procedure for the NSC; a detailed description of the cost estimation development process and procedure; and presentation of a case study that validates the verifies the procedure.

Each task in the project corresponds with a section of this document, as shown in ***Figure 1-1***. The project began with the development of a quality assurance project plan (QAPP) to define objectives, schedule, and deliverables of the project. The literature review (**Section 2**) provides an overview of existing literature and cost tool documentation for primary and secondary cost data (existing data that will be used for purposes other than which they were originally collected) as it pertains to influential cost variables that are relevant for inclusion in a national tool that includes comparative costs. This literature review was completed with the intent that the level of detail of cost data should be commensurate with the level of detail provided by the NSC. The literature review is intended to summarize the LID control cost information and identify major design and construction cost factors that contribute to relative cost estimates. The critical review (**Section 3**) analyzes the cost literature information to determine the key variables necessary to develop for a general cost estimation procedure. This includes consideration of whether the information for the variable is readily available and can be determined at the scale of the project. **Section 4** of the document details how cost estimation procedure was developed, describing the procedure's development steps and design, using key variables and current unit cost information. The procedure is verified using case study analysis in **Section 5**.

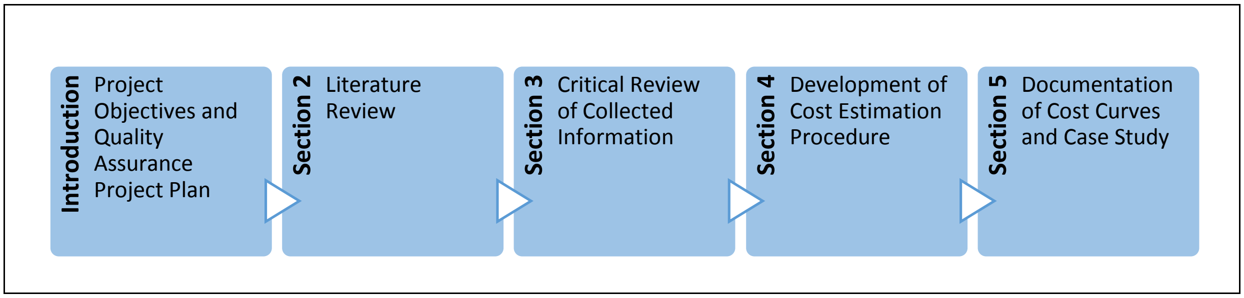


Figure 1-1. Summary of Study Approach and Document Organization

Because of the many mitigating factors that can impact costs (including whether a project or site is undergoing new development, redevelopment, or retrofit; the existing site conditions; and necessary infrastructure to convey inflow and outflow), the costs detailed within this document are not recommended for engineering estimates but are for relative comparison of stormwater controls. It should be noted that due to the nature of a literature review, costs reported in this document are from various dollar years and are not yet converted to a single cost year until they are incorporated into the actual cost curves. During cost curve development in **Section 5**, cost ranges were placed into a data file and converted to a single cost year using RSMeans Building Construction Cost Data (RSMeans, 2014) conversion.

1.2. Development of Project Plan

At the initiation of many research-based projects there is a requirement to develop a QAPP. The project plan typically includes:

- A project description in which the project is described in greater detail to document the expected objectives and tasks to be accomplished that will meet the objectives.
- An organizational and responsibility matrix so that lines of communication are defined early in the project. Often a deliverable schedule is established at this time.
- Communication of the planned scientific approach that will be used in executing the project to assure that the approach is valid and statistically sound.
- Defining the quality of metrics and procedure for data collection. This provides an understanding of the quality of data and establishes the level of confidence or uncertainty in the quality of data.
- A methodology for data management, analysis, and validation. This procedure defines the analytical approach and establishes that adequate precautions are taken to assure the scientific defensibility of data analyses.
- Development of reporting procedures, style, and granularity of interpretation, including the definition of the planned products and the editorial and technical reviews that are performed to deliver a quality product.

The QAPP for this project was prepared in accordance with appropriate EPA documents, including the Guidance for Quality Assurance Project Plans for Modeling and the National Risk Management Research Laboratory (NRMRL) Requirements for Secondary Data. The QAPP was signed by the project team documenting that through QAPP implementation of a quality system in conformance with American National Standards Institute (ANSI)/American Society for Quality Control (ASQC) E4-1994 was established.

2. LITERATURE REVIEW

2.1. Overview

The literature review included staff collection of cost data through Web-based searches to determine and document sources, including peer-reviewed publications, literature that is widely cited by the stormwater LID community, and online data sources. No formal literature search service was used. In addition, existing cost tools and current or previous Geosyntec projects were used as data sources. In this section, we review and report the results and document data quality. Implications of costs and cost factors for variables are documented, and an approach to predicting costs is recommended.

Often the biggest cost factor for implementation of LID controls is whether the LID control is part of a new development project or part of a redevelopment (or retrofit) project. Retrofit projects are not always more expensive if some existing infrastructure can be reused. In some cases, however, it is difficult to use the existing infrastructure because of sizing or location issues with the newly planned development or to bring to the site newer stormwater runoff standards. Often, the costs associated with removing old infrastructure and adding new infrastructure can be high. For example, installation of permeable pavement can be more expensive when existing pavement and sub-base needs to be removed and hauled/disposed before installing the new base course and permeable layer. For green roofs, including a green roof in the building design allows for design and construction. Retrofitting a building with a green roof when structural modifications need to be made to accommodate the additional loading can be a significant investment (Peck and Kuhn, 2001). Similarly, new development vs. redevelopment/retrofit is important for infiltration basins and rain gardens when the space required for pretreatment may be more than what was included in the existing controls (if any). Removing, hauling, and disposing existing infrastructure, adding new infrastructure, and completing new grading for redevelopment or retrofit projects can add significantly to the cost of LID control implementation.

The following LID controls exist within the NSC or have been identified as potential additions to the NSC in the future:

- Rain Gardens (Bioretention)
- Green Roofs
- Infiltration Basins
- Permeable Pavement
- Vegetated Swales (as a future NSC addition)
- Street Planters
- Impervious Area Disconnection
- Rain Harvesting.

The subsections below present the results of a literature review conducted on the costs of these individual LID controls. The following sections will focus on the various costs for implementation (capital and operation and maintenance costs) of each stormwater control, but do not include the costs (or perhaps cost reductions) that are incurred as a result of redevelopment or retrofit project. Similarly, highly variable costs such as land acquisition and permitting are not included in the stormwater control costs detailed in this document. These costs are included in some costing tools, often as a percentage of capital costs.

2.2. LID Controls

2.2.1. Rain Gardens (Bioretention)

Rain gardens (or bioretention cells) are frequently used to reduce runoff volume and peak discharge rate while providing water quality and aesthetic benefits (Southern California Stormwater Monitoring Coalition [SCSMC], 2008). In a study published in 1997 by Brown and Schueler, a survey was administered to local government engineers to develop an empirical relationship between cost and stormwater control measure design volume. Bioretention practices examined by Brown and Schueler (1997) showed that construction costs were highly dependent upon the excavation and additional needs to provide adequate water quality capture volume (WQCV). The study stated that, in general, bioretention practices cost $6.40 per cubic foot of water quality treatment, although information on what components of design, permitting, and/or construction costs were included in that unit cost was not specified (Brown and Schueler, 1997). More recent sources state that rain gardens cost approximately $3-$4 per square foot for simple residential designs installed by the homeowner, and $10-$40 per square foot for commercial designs installed by a professional (Low Impact Development Center [LID Center], 2014). The higher cost of commercial designs can be attributed to the need for control structures, curbing, and piped conveyance (LID Center, 2014). Other factors that influence the cost of rain gardens include site characteristics (and guidance for design criteria) such as impermeable liners, inlet protection, side slope protection, or the need for a concrete retaining walls and side revetments for sites with constrained space (Iowa Stormwater Partnership, 2008; Lake Superior Streams, 2014). The need for other functional features such as pretreatment and underdrains for bioretention facilities can also increase project costs (LID Center, 2014; North Carolina Division of Soil & Water Conservation [NC-DSWC], 2006). Rain gardens built on soils with adequate infiltration rates generally do not need underdrains and, therefore, tend to have lower costs (NC-DSWC, 2006).

The following list presents characteristics that are representative of the simple, typical, and complex design scenarios:

- **Simple:** High infiltrating soils, shallow side slopes requiring limited reinforcement (e.g., 3:1), greater ponding depth, decreased media coverage or depth, simple landscaping. (Note: some factors that result in lower cost can also result in lower performance.)
- **Typical:** Moderate infiltrating soils, shallow side slopes (e.g., 3:1), typical media depth, underdrain, required pretreatment.
- **Complex:** Low infiltrating soils, concrete retaining walls or other reinforced walls required, low ponding depth, high media depth, required pretreatment (sediment forebay), underdrain, impermeable membrane, outfalls/outlet structure, complex landscaping.

2.2.2. Green Roofs

Green roofs capture and store stormwater runoff to reduce runoff volumes (Virginia Department of Environmental Quality [Virginia DEQ], 2011b). Green roofs are often referred to as extensive (i.e., thin growing medium, little or no irrigation, and low plant diversity) or intensive applications (i.e., deep growing medium, irrigation, and high plant diversity including trees) (Peck and Kuhn, 2001; NC-DSWC, 2006). Thus, one of the main factors affecting the cost of green roofs is the thickness of the soil media (Peck and Kuhn, 2001). For inaccessible, extensive green roofs, costs range from $22.25 to $42.00 per square foot and for accessible, intensive green roofs, costs range from $61.25 to $309 per square foot (Peck and Kuhn, 2001). Similarly, a study conducted by the General Services Administration (GSA) found that an extensive green roof installation with 3 inches of soil media was $6 to $8 cheaper per square foot than an intensive green roof installation with 6 inches of soil media (General Services Administration [GSA], 2011). Other studies confirm that type and depth of growing medium affect cost (Green Roofs for Healthy Cities, 2006). Another major variable of green roofs that affects cost is the type of plants installed and the irrigation required by those plants (GSA, 2011; Peck and Kuhn, 2001). Therefore, literature indicates that the cost of a green roof is greatly influenced by landscaping options, which are a reflection of the purpose of the roof. Green roofs can be used for runoff reduction purposes or other purposes such as energy savings, aesthetics, or meeting landscape goals or requirements (Water Environment Research Foundation [WERF], 2009). Green roofs are one of the more costly stormwater control measures, although installations costs are trending lower in some areas with increased knowledge and completed projects. As expected, the unit cost of the installation of green roofs decreases as the size of the green roof increases (GSA, 2011).

The following list presents characteristics that are typical of the simple, typical, and complex design scenarios:

- **Simple:** Extensive green roof with shallow soil profile (e.g., 3 in), no irrigation, low planting density.
- **Typical:** Deep soil profile (e.g., 6 in) or shallow soil profile with irrigation, moderate plant density.
- **Complex:** Intensive green roof with deeper soil profile (e.g., 6 in or more), irrigation system, high plant density (aesthetic purposes).

2.2.3. Infiltration Basins

Infiltration basins are impoundments that infiltrate stormwater runoff using the existing soil infiltrating capacity over a relatively short period following rainfall (typically within 1 to 2 days after a rainfall event). Because native soil is used, and little infrastructure is required, infiltration basins are relatively cost-effective stormwater controls in cases where they are feasible from a soils, groundwater, space, and topographic perspective (U.S. Environmental Protection Agency [U.S. EPA], 2014a). Volume is one of the biggest cost factors in an infiltration basin because significant excavation and earthwork (e.g., building the berm around the basin) may be needed to accommodate the entire runoff volume from a design storm (Young et al., 1996). The importance of excavation in cost estimates can result in a wide difference between the cost of implementing infiltration basins as redevelopment (where soil must be hauled away) versus new development where cut and fill can be balanced on site. Additional existing site conditions such as new or modified infrastructure required to route runoff to or from the infiltration basin will also impact cost (Federal Highway Administration, 2014). Pretreatment will also add to the cost of an infiltration basin, but pretreatment is important to prevent failure and increase the life of the infiltration basin (U.S. EPA, 2014a). Pretreatment may be required by local stormwater management regulations or be important to include for sites where runoff includes greater sediment loads. Literature costs range from $1.80 per cubic foot of water to $21 per cubic foot of water (U.S. EPA, 1999a; Minnesota Pollution Control Agency [MPCA], 2011).

The following list presents characteristics that are typical of the simple, typical, and complex design scenarios.

- **Simple:** High infiltration rate, no pretreatment, natural depressed area/little earthwork necessary.
- **Typical:** Moderate infiltration rate, pretreatment (e.g., grass buffer or forebay), some earthwork necessary to capture runoff.
- **Complex:** Low infiltration rate, pretreatment (e.g., grass buffer, forebay, or hydrodynamic separator), earthwork necessary to capture runoff.

2.2.4. Permeable Pavement

Permeable pavement includes different porous pavement types, including porous concrete, porous asphalt, and interlocking pavers. The type of permeable pavement chosen typically has the biggest influence on cost, with porous concrete costs ranging from $2-$6.50 per square foot and interlocking concrete paving blocks costs $5-$10 per square foot (WERF, 2009). Porous concrete is a more expensive material than porous asphalt, partially because porous concrete is typically thicker and more permeable than porous asphalt (SCSMC, 2008; Virginia DEQ, 2011d). Costs reported from the San Diego County estimate the cost of porous asphalt and porous concrete to be $8.80 per square foot and $14.14 per square foot (SCSMC, 2008). Interlocking pavers often have the highest cost and have a similar useful life as porous concrete (Virginia DEQ, 2011d). Costs for installation were estimated to be $8.00 to $12.00 per square foot for permeable concrete or interlocking pavers with a six-inch gravel layer (NC-DSWC, 2006). Aside from the pavement type, other major factors that influence the cost of a permeable pavement system is the depth of stone reservoir (gravel layer), pretreatment type (if necessary), underdrain number and type, and excavation (SCSMC, 2008).

The following list presents characteristics that are associated with simple, typical, and complex cost scenarios.

- **Simple:** Application of porous asphalt, cut-fill balance (very little hauling).
- **Typical:** Application of porous concrete, no to moderate excavation/hauling volumes, inclusion of outlet structure, basic cleanout access.
- **Complex:** Porous concrete or interlocking pavers, filtering layer, high excavation/hauling volumes, outlet structure, numerous cleanout access points, observation wells.

2.2.5. Vegetated Swales

Vegetated swales (sometimes referred to as grassed swales) are primarily used to reduce runoff velocity, reduce infrastructure, and infiltrate runoff (LID Center, 2000). Vegetated swales typically cost less than traditional stormwater conveyance (LID Center, 2000; Portland Bureau of Environmental Services [BES], 2006; Pennsylvania [DEP], 2006). Construction costs, excluding clearing, grubbing, and filling, for a vegetated swale range from $4.50 - $8.50 per linear foot (LF) if vegetated with seed, and $15 - $20 per LF if vegetated from sod (Pennsylvania DEP, 2006). Turf reinforcement matting is needed if velocities in the swale are expected to be above 4.0 feet per second, and this will increase cost by about $0.50 per square foot (DWSC, 2006). Another study reported costs that vary from $8.50 to $50.00 per LF (Southeastern Wisconsin Regional Planning Commission [SEWRPC], 1991). These estimates include costs such as clearing, grubbing, filling, and sodding. If desired, an increase in volume control and water quality performance can be achieved through the use of an aggregate bed or trench, but this will increase the cost of the swale (Pennsylvania DEP, 2006).

The following list presents characteristics that are associated with simple, typical, and complex cost scenarios.

- **Simple:** Vegetated with seed, minimal or no excavation and hauling of material required.
- **Typical:** Vegetated with sod, some excavation and hauling of material required.
- **Complex:** Check dams, turf reinforcement matting, high excavation and hauling requirements, aggregate bed and/or amended soil media.

2.2.6. Street Planters

Street plants are similar to bioretention, but typically have vertical concrete walls and are located within the street right of way. Street planters contain a soil-growing medium and gravel for storage and filtration of stormwater runoff. The benefits of a street planter include treatment of stormwater runoff and reduction in peak flow rate, a small footprint, and improved aesthetics of streets and sidewalks (LID Center, 2005). Street planters are more expensive than other stormwater practices because of the infrastructure requirements of piping, waterproofing near building foundations, and concrete vaults (Oregon State

University Extension, 2011). The City of Portland has constructed several green street projects with costs of about $30 per square foot for stormwater planters (this cost was also reported as $1.83 per square foot of impervious area managed; BES, 2005a). Another street planter project in the City of Portland was reported to cost $3.64 per square foot of impervious area managed, demonstrating that the costs can be quite variable (BES, 2005b). In general, the City of Portland estimates that their “green street” facilities cost about $44 per square foot to construct (Sustainable City Network, 2011). Others have found that street planters used in an area with infiltrating soils and not near a building foundation can be built with no floor, which may reduce costs (Truckee Meadows Regional Planning Agency [TMRPA], 2007).

The following list presents characteristics that are associated with simple, typical, and complex cost scenarios.

- **Simple:** Street planter with no floor (built on infiltrating soils, not near building foundation), decreased media depth, lower incremental landscape costs based on amount and type of vegetative cover.
- **Typical:** Street planter with underdrain and waterproofing, moderate media depth, moderate incremental landscape costs based on amount and type of vegetative cover.
- **Complex:** Street planter with underdrain and waterproofing, high media depth, high incremental landscape costs based on amount and type of vegetative cover.

2.2.7. Impervious Area Disconnection

Impervious area disconnection is a practice in which runoff from an impervious surface is routed to a pervious surface, through grading or other means (TMRPA, 2007, Virginia DEQ, 2011a). Impervious area disconnection can also include removal of impervious surfaces such as pavement used for driveways, sidewalks or patios (NC-DSWC, 2006). Some examples of impervious area disconnection include routing roof drains to pervious area such as lawns or rain gardens, removing impervious surfaces such as pavement, and decompaction of soils that provide very little infiltration (TMRPA, 2007). The cost to remove impervious pavement surfaces was estimated to be between $2.40 and $6.50 per square foot for various regions in North Carolina (NC-DSWC, 2006). The estimates included costs for surface and gravel removal, hauling and disposal, new soil, regarding, and grass seed application (NC-DSWC, 2006).

The following list presents characteristics that are associated with simple, typical, and complex design scenarios.

- **Simple:** Routing downspouts to pervious area such as lawn or garden.
- **Typical:** Routing downspouts to pervious area such as lawn or garden, decompaction of existing pervious area.
- **Complex:** Pavement removal and routing downspouts to pervious area such as lawn or garden that have undergone soil decompaction; may include rate of runoff controls such as rain barrels or cisterns.

2.2.8. Rain Harvesting

Rain harvesting systems are used to capture runoff and store it for other uses including irrigation. One of the main costs associated with rain harvesting is the size of the tank or cistern used (Texas Water Development Board (TDWB), 2005). The cost of cisterns varies, depending upon material, but typically, costs are between $0.75 and $3 per gallon (gal) of storage (U.S. EPA, 2013b; Hunt and Szpir, 2006). The cost per gallon of storage decreases as cistern size increases (U.S.EPA, 2013b; Virginia DEQ, 2011c; Texas Water Development Board, 2005). Other cost factors such as filtration, pumps, distribution plumbing, and excavation can add an additional $2–$5/gal storage to the cost of the cistern (U.S. EPA, 2013b; TDWB, 2005). These factors are often related to end use and regulations. Installation can be another large cost factor for implementation of rain harvesting, especially if the cistern is to be installed underground (NC-DSWC, 2006). It should be noted that rainwater harvesting for indoor or potable use may require additional treatment that is not considered in this analysis.

The following list presents characteristics that are associated with simple, typical, and complex design scenarios:

- **Simple:** Above-ground plastic cistern, simple gravity-fed outdoor irrigation use.
- **Typical:** Above-ground or buried cistern, minimal treatment requirements, pumped distribution system with minimal elevation changes.
- **Complex:** Above-ground or buried cistern, treatment requirements including filtration and/or disinfection, extensive pumped distribution system with moderate elevation change.

2.2.9. Summary

Table 2-1 includes a summary of the simple and complex design cost data reviewed in **Sections 2.1.1-2.1.8**. The costs in ***Table 2-1*** include construction costs only (e.g., excavation, hauling, soil media, plantings) and reflect the cost of new development projects. Most costs are expressed as cost per square foot of LID Control constructed. Additional cost data is provided in the following sections as part of a review of the existing cost tools. Note that typical costs are not included in this table. At this stage, providing a range of values is most appropriate for costs that cover a national scale due to the variability between site conditions, design standards, labor, and material costs, etc.

Table 2-1. Summary of Literature Review of Construction Cost Data for New Development

LID Control	Simple	Complex	Major Cost Factor	Sources
Rain Gardens (bioretention)	$3/ft2	$40/ft2	size, as well as infrastructure such as underdrains or outlet structures	Brown and Schueler, 1997; NC-DSWC, 2006; Iowa Stormwater Partnership, 2008; Lake Superior Streams, 2014; LID Center, 2014
Green Roofs	$9.60/ft2	$40/ft2	media depth and plantings (extensive vs. intensive)	NC-DSWC, 2006; GSA, 2011; Peck and Kuhn, 2001; Virginia DEQ, 2011b
Infiltration Basins	$1.30/ft2	$11/ft2	size	U.S. EPA, 1999a; MPCA, 2011;
Permeable Pavement	$2/ft2, $7/ft3 (volume of water captured)	$16/ft2, $27/ft3 (volume of water captured)	type of permeable pavement	MPCA, 2011; SCSMC, 2008; WERF, 2009
Vegetated Swales	$5/LF	$50/LF	size	NC-DSWC, 2006; Pennsylvania DEP, 2006; SWRPC, 1991
Street Planters	$30/ft2	$50/ft2	Size and vegetation	BES, 2005a; WERF, 2009
Impervious Area Disconnection	$2.40/ft2 of pavement removal	$6.50/ft2 of pavement removal	type of impervious area disconnection	NC-DSWC, 2006 (based on pavement removal)
Rain Harvesting	$0.50/gal of storage	$8/gal of storage	type of cistern, distribution system	Hunt and Szpir, 2006; TWDB, 2005, U.S. EPA, 2013b

ft^2 = square feet LF= linear feet
ft3 = cubic feet gal = gallons

2.3. Current Cost and Performance Tools

Models, including both unitized cost data and performance data, can provide information on the range of costs for LID controls based on capital, operation, and maintenance costs. Cost data and models that have been previously developed for LID controls that were sourced for this project included the Water Environment Research Foundation's (WERF) Best Management Practices (BMP) and LID Whole-Life Cost (WLC) Model; Green Roofs for Healthy Cities GreenSave Calculator*;* the Center for Neighborhood Technologies (CNT) National Green Values™ Calculator; System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN); Structural BMP Prioritization and Analysis Tool (SBPAT); and Best Management Practices Rational Estimation of Actual Likely Costs of Stormwater Treatment (BMP-REALCOST). A summary of the tools and examples of cost components included in each tool are presented in ***Table 2-2*** and ***Table 2-3***. A description of the data sources and the cost ranges for individual stormwater controls are summarized in the following sections for each tool. ***Table 2-3*** is not intended to be an exhaustive list of cost components included in the cost tools, but rather, provides a sense of which tools include costs such as engineering, design, permitting etc. in the cost analysis. Note that many of the tools include unit cost components beyond excavation, hauling/disposing, mulch/seed/plants, pretreatment, and outlet structure.

Table 2-2. Summary of LID Control Cost Tools

Cost Tool	Cost Type(s)	Reg.	National	Cost Data Source	Cost Data Year	Normalized by
WERF Whole-Life Cost Tool	Capital, O&M		•	Costs from literature sources or user entered line items	2008	Varies
GreenSave Calculator	Capital, Maintenance	•		User entered costs only	User defined	Total project cost
CNT Green Values™	Capital, Maintenance		•	Costs from literature sources	Unknown	Area
SUSTAIN	Capital		•	Costs from literature sources or user entered line items	2007	Area (square foot constructed)
SBPAT	Capital, Maintenance	•		Cost from literature sources	2005	Area (per acre treated)[a]
BMP REALCOST	Capital, Maintenance		•	Costs from Denver projects adjusted to National-level	2008	Varies

[a] While reported in the tool documentation as cost per acre, SBPAT normalized LID performance by volume or flowrate (if a flow-based BMP such as a swale).

Table 2-3. Summary of Cost Components Included in LID Control Cost Tools

Potential Cost Components	WERF Whole-Life Cost Tool	Green Values™	SUSTAIN	SBPAT	BMP-REALCOST
Excavation	●	●	●	●	●
Hauling	●	●	●	●	
Plants/Seed/Mulch	●	●	●	●	●
Pretreatment/Forebay (if applicable)	●	●	●	●	●
Outlet Structure (if applicable)	●	●	●	●	●
Engineering/Design	%			%	%
Permitting	%			%	%
Contingencies	%			%	%
User Input Allowed	●		●	●	

% = Cost component is determined as a percentage of capital cost

2.3.1. WERF (in partnership with the U.S. EPA) Best Management Practices and LID Whole-Life Costs Models

The WLC models are spreadsheet tools that use capital costs and operation and maintenance expenses to determine the whole life cost of a stormwater control measure per BMPs. The BMPs included in the model are extended detention basin, retention pond, swale, permeable pavement, bioretention, green roofs, in-curb planter vault, and cisterns. The model offers two operational modules: the "generic application," which generates planning-level estimates, or the "site-specific application," where custom values are entered by the user to get a more accurate life-cycle cost estimate. User inputs for the generic application include, but are not limited to, system size, system type, drainage area, and capital and/or maintenance costs, if available. If the user does not specify capital or maintenance costs (i.e., site specific application), the total cost of the BMP is estimated by multiplying the unit cost per area by the area of the BMP. The unit cost that is used for the general estimate is generated through user-defined design options. For example, rain garden costs are based on installation method, scale (e.g., single house, neighborhood), and level of maintenance. Engineering, permitting, and other contingency costs are not included in the generic application module but can be included by the user if using the site-specific module. Costs were normalized to area or volume and adjusted to 2008 dollars. Maintenance costs are calculated on an annual basis. Users define the level of maintenance (i.e., low, medium, or high), and the costs include but are not limited to maintenance frequency, hours per maintenance event, crew size, and labor rate. ***Table 2-4*** and ***Table 2-5*** present the capital and maintenance cost data used in the WERF – WLC Model. Normalized unit costs include converting the cost data to one common unit of measure and applying RSMeans to report all values as the same cost year (2008).

Table 2-4. WERF Whole-Life Cost Tool Data and Sources

LID Control (normalized cost unit)	Sources*	Cost per Normalized Unit
Rain Garden (cost per square foot)	Edgewood College, 2003; Kassulke, 2003; EPA, 2008; James City County, 2008; RSMeans, 2008	Self-Installation: $0.50–$8.83 (avg: $5.15) Professional Installation: $8.00–$40 (avg: $16.05)
Cisterns (cost per gallon)	Darco Underground Tankage, Inc., 2008; Hicks, 2008; Nicklas, 2008; RSMeans, 2008	Tank costs: $1.33–$2.51 per gallon
Curb Contained Bioretention (cost per acre of drainage area)	Bannerman, 2003; United Facilities Criteria (UFC), 2004; U.S. EPA, 2000; Heaney, 2002; RSMeans, 2008	No Underdrain: $34,700–$51,486 (avg: $42,254) With Underdrain: $48,00–$139,000 (avg: $89,000)
Extended Detention Basin (cost per acre of drainage area)	not listed	$1,000 – $3,000
Green Roof (cost per square foot)	Banting et al., 2005; BES, 2008; Fairfax County, 2005; Peck and Kuhn, 2008; Roofscapes, 2008; SPU, 2008; Toronto and Region Conservation, 2008; RSMeans, 2008	$19.50–$50.85
In-curb Planter Vault (cost per vault)	Calkins, 2008; BES 2005a; U.S. EPA, 2005; Fairfax County, 2005; UFC, 2004; RSMeans, 2008	$10,000
Permeable Pavement (cost per square foot)	LID Center, 2004	$0.50–$10.00
Retention Pond (cost per acre of drainage area)	not listed	$1,000–$3,000
Swale (cost per acre of drainage area)	not listed	$1,000–$3,000

* *As reported in* Water Environment Research Foundation (WERF). (2008). BMP and LID whole life cost models, version 1.0. Alexandria, Virginia.

Table 2-5. WERF Whole-Life Cost Tool Annual Maintenance Costs[a]

LID Control	Annual Maintenance Costs per LID Control
Rain Garden	$0–$3,840
Cisterns	$345–$11,280
Curb Contained Bioretention	$80–$3,810
Extended Detention Basin	$183–$42,260
Green Roof	$670–$19,320
In-curb Planter Vault	$117–$1,155
Permeable Pavement	$98–$2,660
Retention Pond	$183–$52,520
Swale	$150–$6,020

[a] 2008 dollars

2.3.2. Green Roofs for Healthy Cities *GreenSave Calculator*

The *GreenSave Calculator* does not estimate the cost of a green roof like other tools. Rather, it compares the total life cycle cost of a green roof versus other conventional roofing methods. This tool uses a life cycle costing (LCC) method that takes into account the costs and benefits of each roof type and allows the user to determine what type of roof is a better investment. User inputs to the tool include total installed capital cost, annual electricity energy cost, storm water control (mitigation grant or annual feebate), annual maintenance costs, roof replacement interval, and more. Unlike other tools, the user must enter the total installed capital cost, annual maintenance costs, and periodic replacement costs. The tool takes into account the study period, applicable discount rate, and price inflation factors for electricity and fuel in order to calculate the net present value (NPV), the payback period on investment, and the internal rate of return (IRR) on investment. More information on this tool can be found in the Green Roofs for Healthy Cities Report entitled "Applying LCC to Roofing Investments: A Guide to Using Green Roofs for Healthy Cities *GreenSave Calculator*" (Green Roofs for Healthy Cities, 2007). This calculator was reviewed but was not found to contain cost data relevant to this literature review.

2.3.3. The CNT National Green Values™ Calculator

The Green Values™ Calculator developed by the CNT (2009) is an online tool that allows users to compare the cost and performance of various LID practices to conventional stormwater management practices. The LID controls available in the Green Values™ Calculator are green roofs, planter boxes, rain gardens (bioretention), cisterns, native vegetation, filter strips, amended soil, swales, trees, permeable pavement, and reduced street width. Inputs to the Green Values™ Calculator are similar to those for the EPA Stormwater Calculator, including location information (e.g., precipitation, soil type, and land cover) and proposed green infrastructure characteristics. The Green Values™ Calculator does require the user to input the size (area) of the project site, unlike the EPA Stormwater Calculator, which uses a unit approach based on an assumed lot size of 10 acres unless otherwise specified. Performance of LID controls is evaluated through the runoff volume capture capacity, which is treated as a static volume not influenced by infiltration. Costs are calculated per square foot of control, not per volume of stormwater captured as in some other tools because the tool does not calculate the drainage area served by each LID control.

The cost component of the tool includes both construction and maintenance costs for each LID control. Unlike some other tools, the Green Values™ Calculator does not allow users to manually customize cost data. Metadata for the construction and maintenance costs used in the Green Values™ Calculator is summarized in ***Table 2-6*** and ***Table 2-7***, respectively. Complete cost metadata can be found in the National Green Values™ Calculator Methodology document. It should be noted that some specific cost data were not included in the Green Values™ Methodology document.

Table 2-6. CNT Green Values™ Capital Cost Data and Sources

LID Control	Sources	Cost per Normalized Unit
Green Roofs	BES, 2005a; BES, 2008; City of New York, 2008; Wetland Studies and Solutions, Inc. (WSSI), 2007	\$372,000–\$2,300,000/acre managed; or \$4.00–\$31.80/ft^2 of green roof built
Planter Boxes	BES, 2005a; WERF, 2007	\$33,880–\$184,700/acre treated; or \$77/ft^3 of storage
Rain Gardens (Bioretention)	Louisville and Jefferson County Metropolitan Sewer District, 2009; Seattle Public Utilities (SPU), 2008; WERF, 2007	\$175,465/area managed, \$2.58–\$20/ft^2
Cisterns	BES, 2005a; City of New York, 2008; WSSI, 2007	\$53,600–\$171,000/acre treated; or \$0.37–\$0.77/gal/yr
Native Vegetation	N/A	cost savings are associated with reduced runoff volume

(continued)

Table 2-6. CNT Green Values™ Capital Cost Data and Sources (continued)

LID Control	Sources	Cost per Normalized Unit
Filter Strips	U.S. EPA, 2014b	Low cost from establishment from seed ($13,000/ac), mid costs from establishment from sod ($30,000/ac)
Amended Soil	LID Center[a]	low costs for compost amended soil, high costs quoted for Department of Ecology specified mix of mineral aggregate, perlite, dolomite and gypsum
Swales	WSSI, 2007; BES, 2005a; City of New York, 2008	$16,500–$160,300/acre managed; or $5.50–$18.73/ft^2 of swale
Trees	United States Department of Agriculture, 2006	$0.30–$400 each
Permeable Pavement	WERF Whole-Life Cost Model, 2008; City of New York, 2008; SPU, 2008	$28,780 –$570,000/acre managed; or $1.48–$8.13/ft^2
Reduced Street Width	N/A	cost savings are associated with reduced runoff volume and infrastructure costs

[a] Complete citation not available
N/A – Not available

Table 2-7. CNT Green Values™ Maintenance Cost Data and Sources

LID Control	Source	Maintenance Cost Estimate
Green Roofs	BES, 2005a; BES, 2008; City of New York, 2008	$0.025–$2.89/ft^2 of green roof
Planter Boxes	BES, 2005a; WERF, 2008	$660–$1,830/acre treated
Rain Gardens (Bioretention)	BES, 2006; SPU, 2008; WERF, 2008	$2,744/acre of impervious area managed; or $1.45–611/ft^2
Cisterns	SPU, 2008	$200 per installation
Native Vegetation	N/A	N/A
Filter Strips	N/A	N/A
Amended Soil	N/A	N/A
Swales	WERF Whole-Life Cost Model, 2008;	$527–$2,744/acre treated
Trees	N/A	N/A
Permeable Pavement	LID Center, 2005; SPU, 2008	$4,000/acre managed; or $0.05–$500/ft^2
Reduced Street Width	N/A	N/A

N/A – Not available

2.3.4. System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN)

SUSTAIN is a geographic information systems (GIS)–based model used to determine optimal LID controls based on performance and cost. LID controls that are included in the tool are constructed wetlands, infiltration basins and trenches, bioretention cells, sand filters, rain barrels/cisterns, wet and dry ponds, grassed swales, vegetated filter strips, permeable pavement, and green roofs. Due to the lack of uniformity in LID control cost data, SUSTAIN uses unit cost data derived from unit costs provided by wholesale and retail companies and also from literature and LID manuals. Cost is determined on a per square foot of LID control basis. Cost information is limited to construction cost only. Users have the ability to override cost data and enter their own. In addition, users can choose to have cost estimates include information from all data in the cost database or from only select sources within the cost database. Examples of cost components include, but are not limited to, excavation, grading, soil/media, gravel, underdrain, mulch, trees/shrubs/plantings, inlet and outlet structures, and porous paving material. The sources for cost data are listed below:

Wholesale/Retail Bulk Material Pricing (compiled in 2007)

- EPA Stormwater Technology Fact Sheets (U.S. EPA, 1999b, http://water.epa.gov/scitech/wastetech/mtbfact.cfm)
- California Department of Transportation (Caltrans) (Caltrans, various years, http://www.dot.ca.gov/)
- Fairfax County BMP Fact Sheets (Fairfax County, 2005, http://www.lowimpactdevelopment.org/fairfax.htm#ffxfactsheet)
- Natural Resources Conservation Service (NRCS) Cost Share Data (NRCS, various years, http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home/)
- Michigan Department of Environmental Quality (DEQ)'s 319 BMP Cost Database (Michigan DEQ, various years, http://www.michigan.gov/deq/0,4561,7-135-3313_3682_3714-101788--,00.html)
- EPA's Heat Island Website (U.S. EPA, http://www.epa.gov/heatislands/mitigation/greenroofs.htm)
- Great Lakes Institute's Website (McLellan Lab at University of Wisconsin, Milwaukee, http://home.freshwater.uwm.edu/mclellanlab/green-roof/#costs)
- *Minnesota Stormwater Manual* (Version 2.0) (MPCA, 2008).

Cost estimate data were not readily available in literature sources or tool documentation; however, many of these sources are used in other tools that are included in this document.

2.3.5. Structural BMP Prioritization and Analysis Tool (SBPAT)

SBPAT is a GIS-based tool developed for the Los Angeles, California, region and is used to prioritize LID controls in urbanized watersheds and to quantify benefits, risks/uncertainties, and costs associated with LID projects. LID controls are ranked based on cost, performance, and maintenance requirements. LID controls available for analysis include distributed facilities such as cisterns, bioretention cells, vegetated swales, green roofs, porous pavement, manufactured separation systems, catch basin inserts and media filters, as well as regional facilities such as infiltration basins, dry detention basins, subsurface flow wetlands, constructed surface flow wetlands, hydrodynamic devices, and channel naturalization.

The capital cost estimation component is based upon regression equations found in literature and on unit construction costs derived from RSMeans (2005). Cost estimates were then normalized by area to find the capital cost per acre treated. Some capital cost estimations were tailored to the region using RSMeans values to regionalize cost data from literature sources to the region based on itemized cost estimates. Maintenance cost information was based on literature, but also on professional opinion when literature values were unavailable. Maintenance costs were normalized on an annual basis. Costs used in SBPAT are in 2005 dollars, and regional cost adjustment factors from U.S. EPA (1999a) were applied to find costs representative of Southern California.

Table 2-8 and ***Table 2-9*** present the normalized capital cost per acre treated and the annualized maintenance costs, respectively, used for SBPAT.

Table 2-8. SBPAT Capital Cost Data and Sources (Reported in 2005 Dollars)

LID Control	Source	Normalized Cost per Acre Treated
Distributed		
Cisterns	RSMeans, 2005 itemized cost estimate	$7,800
Bioretention	U.S. EPA, 2004	$23,100
Vegetated Swales	RSMeans, 2005 itemized cost estimate	$2,600
Green Roofs	BES, 2000	$223,300
Porous Pavement	U.S. EPA, 2004	$31,000
Manufactured Separation Systems	Bannerman et al., 2003	$44,700
Catch Basin Inserts	RSMeans, 2005 itemized cost estimate	$1,100
Media Filters	RSMeans, 2005 itemized cost estimate	$9,600
Regional		
Infiltration Basins	RSMeans, 2005 itemized cost estimate	$3,700
Dry Detention Basins	RSMeans, 2005 itemized cost estimate	$2,100
SSF Wetlands	Susilo et al., 2004	$28,800
Constructed SF Wetlands	RSMeans, 2005 itemized cost estimate	$2,300
Hydrodynamic Devices	Average cost of four commonly used technologies (manufacturer not specified)	$10,300
Channel Naturalization	RSMeans, 2005 itemized cost estimate	$2,300

Table 2-9. SBPAT Maintenance Cost Data and Sources (Reported in 2005 Dollars)

LID Control	Source	Annual Maintenance Cost Estimate
Distributed		
Cisterns	Geosyntec Consultants, 2008	$100
Bioretention	Bannerman et al., 2003	$2/ft (0.05/ft^2)
Vegetated Swales	SEWRPC, 1991	5–7% of Capital Cost, $0.58–$0.78/ft
Green Roofs	Assumed similar to bioretention	$2/ft (0.05/ft^2)
Porous Pavement	Bannerman et al., 2003	$290/acre of practice
Manufactured Separation Systems	Bannerman et al., 2003	$2,200/practice
Catch Basin Inserts	California Stormwater Quality Association, 2003	$50–$500/practice
Media Filters	Geosyntec Consultants, 2008	$1,500/acre treated
Regional		
Infiltration Basins	Livingston et al., 1997; SEWRPC, 1991	1–3% of capital cost
Dry Detention Basins	Wiegand et al., 1986; Schueler, 1987; SEWRPC, 1991	<1% of capital cost
SSF Wetlands	U.S. EPA, 2000; WEF, 2000	$1064/acre of practice
Constructed SF Wetlands	Wiegand et al., 1986; Schueler, 1987; SEWRPC, 1991; Livingston et al., 1997; Brown and Schueler, 1997	2–6% of capital cost
Hydrodynamic Devices	Bannerman et al., 2003	$500/practice
Channel Naturalization	Unit costs assumed to be cheaper than dry detention	<1% of capital cost

2.3.6. BMP-Rational Estimation of Approximate Likely Costs of Stormwater Treatment (BMP-REALCOST)

BMP-REALCOST (Olson et al., 2013) is a spreadsheet-based tool that provides BMP performance (volume and pollutant load reduction) and cost estimates for the Denver, CO, region. The tool compares 10 different stormwater control measure application scenarios in an urban watershed scenario. The stormwater controls that can be evaluated using this tool are extended detention basins, retention ponds, sand filter basins, hydrodynamic separators, inlet inserts, and rain gardens.

BMP-REALCOST uses cost equations where cost is a function of the size of the BMP. In order to create cost equations, cost data were collected from Denver-area construction projects over the course of 5 years, and costs were converted to 2008 dollars and national average costs using the Engineering News Record Cost Comparison Index (ENR CCI) (Engineering News Record, 2008). Unlike other tools, this tool reports "capital cost" as the total cost, including construction costs, land costs, and additional costs attributed to contingencies, engineering, and administration. Users should note that because cost data were collected from projects in the Denver-area, the LID control measures were designed and built to meet Urban Drainage and Flood Control District (UDFCD) design standards (2008). Users do not have the option of entering unit costs into this tool.

Equations were also developed to estimate annual maintenance costs. The annual maintenance cost equations are a function of annual costs for constant and variable maintenance activities, as well as size.

Table 2-10 and ***Table 2-11*** present the construction and annual maintenance cost equations, respectively, developed for BMP-REALCOST. Construction costs presented in ***Table 2-10*** do not include land, contingency, engineering, or administration costs.

Table 2-10. BMP-REALCOST Construction Cost Equations (Reported in 2010 Dollars)

LID Control	Capital Cost Equation
Constructed Wetland Basin	$21,368 + $0.89(V)
Constructed Wetland Channel[1]	$6,700 + $102.70(F)
Extended Detention Basin (WQCV)	$23,897 + $0.89(V)
Extended Detention Basin (EURV)	$26,196 + $0.55(V)
Hydrodynamic Separator	$16,639 + $13,337(F)
Inlet Inserts	$393.32 + $1,967(F)
Media Filter Vault	$30,373 + $57,880(F)
Porous Landscape Detention	$10,729 + $9.93(V)
Retention (Wet) Pond (WQCV)	$23,082 + $0.71(V)
Retention (Wet) Pond (EURV)	$27,884 + $0.46(V)
Sand Filter Basin	$9,861 + $3.55(V)
Sand Filter Vault	$27,046 + $36.26(V)
Sediment/Oil/Grease Separator	$8,851+ $17,960(F)
Vault with Capture Volume	$16,616 + $19.49(V)
Concrete Grid Pavers (Modular Blocks)	$102.86 + $10.10(SA)
Permeable Interlocking Concrete Pavers	$7,257 + $14.23(SA)
Porous Concrete Pavement	$14,409 + $16.49(SA)
Porous Gravel Pavement	$7,258 + $6.87(SA)
Reinforced Grass Pavement	$13,236 + $11.82(SA)

[1]cost per 100 linear feet of channel
WQCV = water quality capture volume
EURV = excess urban runoff volume

V = storage volume (cubic feet)
F = design flowrate (cfs)
SA = surface area (ft^2)

Table 2-11. BMP-REALCOST Annual Maintenance Cost Equations (Reported in 2010 Dollars)

LID Control	Annual Maintenance Equation
Constructed Wetland Basin	$1,956 (AF)
Constructed Wetland Channel	$960 (acre)
Extended Detention Basin (WQCV)	$1,849+$2,782 (AF)
Extended Detention Basin (EURV)	$1,849+$2,782 (AF)
Hydrodynamic Separator	$749 (cfs)
Inlet Inserts	$165 (each)
Media Filter Vault	$835 (cfs)
Porous Landscape Detention	$0.62 (V)
Retention (Wet) Pond (WQCV)	$1,521+$1,598 (AF)
Retention (Wet) Pond (EURV)	$1,521+$1,598 (AF)
Sand Filter Basin	$1,096 (AF)
Sand Filter Vault	$1.86 (V)
Sediment/Oil/Grease Separator	$832 (cfs)
Vault with Capture Volume	$0.66 (V)
Concrete Grid Pavers	$125 (acre)
Permeable Interlocking Concrete Pavers	$125(acre)
Porous Concrete Pavement	$125 (acre)
Porous Gravel Pavement	$5,647 (acre)
Reinforced Grass Pavement	$4,040 (acre)

WQCV = water quality capture volume
EURV = excess urban runoff volume
V = storage volume (cubic feet)
cfs = cubic feet per second
AF = acre feet

2.3.7. Published Literature on LID Control Cost Data

Although published and relevant literature were reviewed above, some sources are examined in greater depth here because they provide relatively complete cost data rather than information relating to only one LID control. These sources are either standalone literature reviews of existing data or compilations of cost data from a particular region.

Stormwater BMP Costs: North Carolina Division of Soil & Water Conservation Community Conservation Assistance Program (NC-DSWC, 2006)

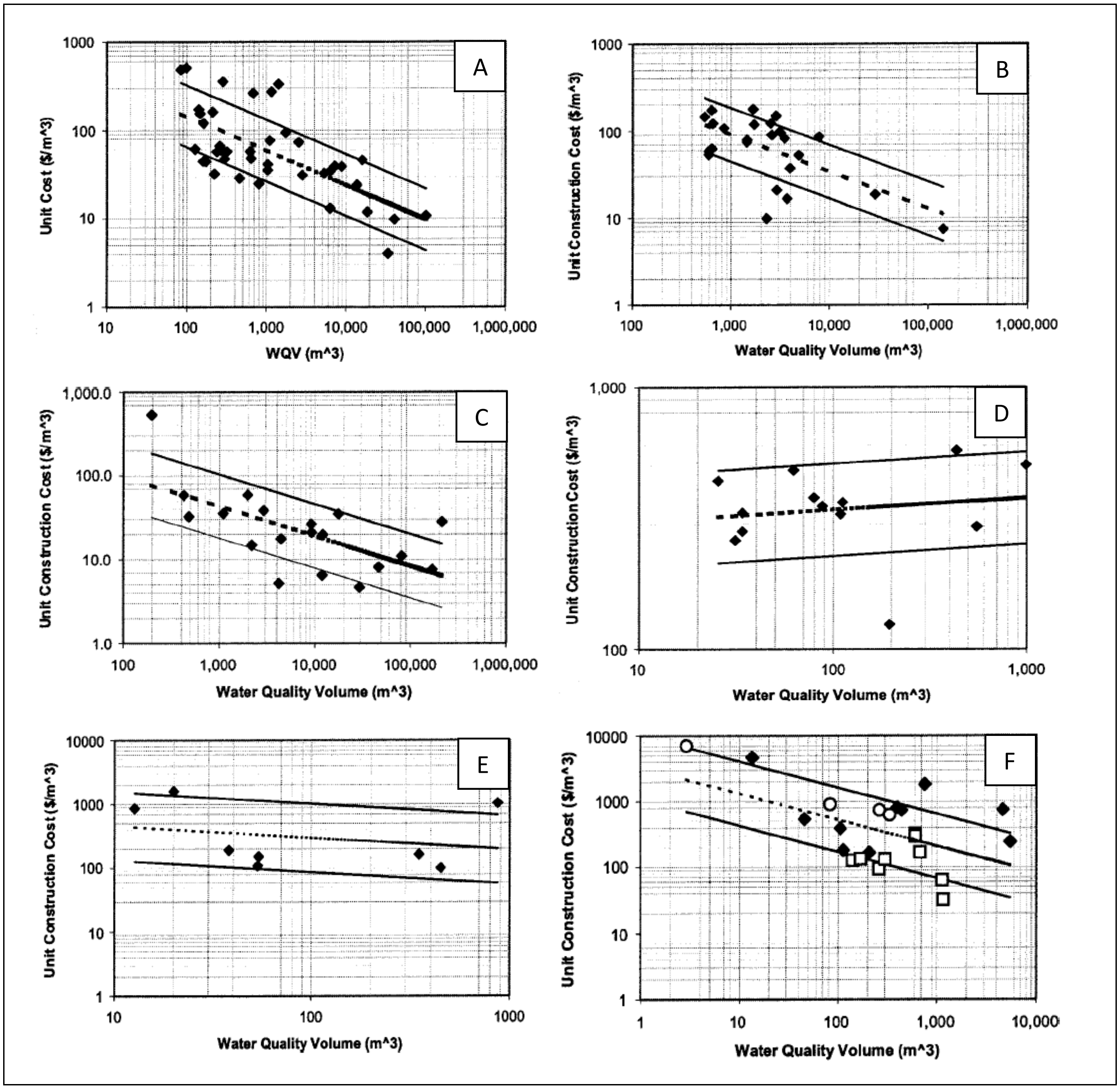
The costs presented in this document are from over 70 installations of "small BMPs" conducted by the North Carolina Cooperative Extension Service (NCCES) for the Division of Soil and Water Conservation (NC-DSWC, 2006). The LID controls evaluated in this document are rain gardens (bioretention), cisterns/water harvesting systems, green roofs, impervious removal, permeable pavement, swales, and pocket wetlands. The construction cost estimates reported in this document are intended for watersheds less than two acres in size (i.e., residential and small commercial applications). Construction costs generally include excavation, hauling, soil amendment, mulch, plants, and other unit costs specific to application (e.g., rain barrel or permeable pavement layer). Costs do not include design and engineering, land acquisition, or permitting. ***Table 2-12*** includes the unitized cost based on installations of LID controls in North Carolina and notes on relevant design information.

Table 2-12. North Carolina DSWC Cost Data (NC-DSWC, 2006)

LID Control	Cost per normalized unit	Notes
Rain Gardens (Bioretention)	$150–$1,000/rain garden	Rain garden size: 25–200/ft^2
Cisterns/Water Harvesting	$300–$2,820/cistern	2,500-gallon rain barrel, does not include pump costs
Green Roofs	$9.60–$19.50/ft^2	4-inch soil layer
Impervious Removal	$2.40–$6.50/ft^2	Pavement removal and disposal, fill soil, re-grading and seed application
Permeable Pavement	$8.00–$12.00/ft^2	Pervious concrete and interlocking pavers
Swales	$0.60–$1.95/ft^2	6–8 feet wide with 1 foot depth, add $0.50 if turf reinforcement matting is required
Pocket Wetlands	$170–$890/wetland	25–200/ft^2

Cost and Pollutant Removal of Storm-Water Treatment Practices: Journal of Water Resources Planning and Management (Weiss et al., 2007)

This journal article develops cost curves based on total construction costs, excluding land acquisition costs. Cost curves were developed using existing published information relating to construction and annual operation and maintenance costs for six types of LID controls: dry extended detention basins, wet/retention basins, infiltration trenches, constructed wetlands, bioretention systems, and sand filters. The costs were reported per unit of water quality volume, defined as the volume of runoff that the LID control is designed to store and/or treat. Construction costs excluded land acquisition, pretreatment units, design/engineering fees, permit fees, and contingencies. Sources of construction cost information include Brown and Schueler, 1997; SEWRPC, 1991; International Stormwater BMP Database, 2007; and Caltrans, 2004. Operation and maintenance costs were estimated as a percentage of total construction cost. The authors reported that the found very little data documenting the actual operation and maintenance costs of installed LID controls, but found general guidelines of estimated annual operation and maintenance as a percentage of total construction cost. ***Figure 2-1*** shows the cost curves developed by Weiss et al., 2007.



(A) dry extended detention basins, (B) wet basins, (C) constructed wetlands, (D) bioretention filters, (E) infiltration trenches, (F) sand filters

Figure 2-1. Cost urves for Six Stormwater Treatment Practices (Weiss et al., 2007)

Best Management Practices Construction Costs, Maintenance Costs, and Land Requirements: Minnesota Pollution Control Agency by Barr Engineering (MPCA, 2011)

This report from the Minnesota Pollution Control Agency (MPCA) provides cost estimates for the following LID controls: bioretention basins; biofiltration basins; large wet detention basins treating more than 100,000 cubic feet; small detention basins treating less than 10,000 cubic feet (ft^3); constructed wetlands; infiltration trenches; infiltration basins; underground infiltration; and pervious pavement. Cost data were obtained from surveys of Minnesota projects and from literature sources, including Weiss and colleagues (2007). Cost data were normalized to the water quality volume, which is the total volume of the BMP below the outlet for bioretention basins, biofiltration basins, infiltration trenches/basins, and underground infiltration structures. Dead storage volume was used for wet detention basins, and the volume of constructed wetlands was found by multiplying the surface area of the wetland by an 18-inch depth. For permeable pavement, the void space of the base aggregate was used as the water quality volume. Costs were reported in 2010 dollars using regional cost factors reported in Weiss and colleagues (2005). Design, geotechnical testing, and legal fees are not included in construction costs in this report. ***Table 2-13*** and ***Table 2-14*** report the average cost per water quality volume and the average annual maintenance costs per cubic foot of water quality volume.

Table 2-13. Minnesota Pollution Control Agency Capital Cost Data (MPCA, 2011; Reported in 2010 Dollars)

LID Control	Average Cost per Water Quality Volume (ft^3)
Bioretention Basins	$15
Biofiltration Basins	$58
Large Wet Detention Basins treating more than 100,000 ft^3	$2
Small Detention Basins treating less than 10,000 ft^3	$145
Constructed Wetlands	$1
Infiltration Trenches	$11
Infiltration Basins	$21
Underground Infiltration	$213
Pervious Pavement	$16

Table 2-14. Minnesota Pollution Control Agency Annual Maintenance Costs (MPCA, 2011; Reported in 2010 Dollars)

LID Control	Annual Maintenance Cost Estimate per Water Quality Volume (ft^3)
Bioretention Basins	$1.25
Biofiltration Basins	No data
Large Wet Detention Basins treating more than 100,000 ft^3	$0.07
Small Detention Basins treating less than 10,000 ft^3	No data
Constructed Wetlands	No data
Infiltration Trenches	$0.39
Infiltration Basins	No data
Underground Infiltration	$1.26
Pervious Pavement	No data

2.3.8. Other Geosyntec Project Information

Many of the Geosyntec projects include LID cost information datasets that have been peer-reviewed and/or include cost estimation procedures and tools that use primary and secondary literature. These include the International BMP Database (www.bmpdatabase.org) and several BMP sizing and costing tools for the National Cooperative Highway Research Program (NCHRP, 2014) and EPA (Geosyntec Consultants, 2011). These projects incorporated quality assurance/quality control (QA/QC) procedures to assure that the approaches, data, and products were of sound quality.

Cost Data Developed with NCHRP 25-40

Long-term performance and life-cycle costs of stormwater best management practices (NCHRP, 2014) are evaluated as another large data source for cost information. The cost approach for this project was based largely on the WERF Whole-Life Cost Model and is tailored to costs and pollutants generated through the treatment of highway runoff. The tool includes bioretention, dry detention, permeable pavement, sand filters, and swales. This tool uses a line-item, user-entered approach to determine capital costs and a low, medium, or high maintenance level to determine maintenance costs. Both this tool and the WERF Whole-Life Cost tool will be used to help develop cost curves for the NSC.

Cost Data Developed under U.S. EPA Contract Number EP-C-08-002, Task Order 21, Evaluation of Stormwater Standards

This EPA-funded project was aimed at evaluating and analyzing the costs and benefits of implementing a nationwide rule for the management of post-construction stormwater runoff. One notable product of this effort was the development and use of a "Least Cost" combination of stormwater control algorithm. This tool facilitates the evaluation of LID control measure costs and pollutant load reductions of implementing alternative control strategies, utilizing green infrastructure and LID techniques on a nationwide basis. LID controls included in this tool are permeable pavement, bioretention basins, cisterns, dry wells, green roofs, infiltration basins, infiltration trenches, sand filters, soil decompaction, underground infiltration galleries, vaults, and wet ponds. The tool included both a new development cost and redevelopment cost components. Literature sources used for this effort were also included in this review. Additionally, cost components of the low, typical, and high cost scenarios developed in this effort were considered for inclusion in the NSC tool. Low, typical, and high unit costs used for the new development scenarios are included in ***Table 2-15***. Typical unit costs for redevelopment scenarios were also included in the table. These costs should be used with caution because the assumptions used to develop the costs may be very different than other project sites and LID designs.

Table 2-15. Cost Ranges for New Development Scenarios (Reported in 2011 Dollars)

LID Control	Rep. Size[a]	Unit Effective Treatment Volume (Volume as ft^3) or Surface Area (Area as ft^2)	New Development			Re-development
			Simple	Typical	Complex	
Bioretention Basin	1000	Volume	$3.00	$8.00	$46.00	$11.00
Cistern	267	Volume	$20.00	$50.00	$175.00	N/A
Dry Well	500	Volume	$4.00	$20.00	$40.00	$27.50
Green Roof*	1000	Area	$7.30	$20.00	$62.00	N/A
Infiltration Basin	3300	Volume	$2.00	$4.50	$12.00	$9.00
Infiltration Trench	380	Volume	$7.50	$10.00	$114.00	$14.00
Permeable Pavement[b]	2000	Area	$1.00	$2.00	$9.00	$2.50
Sand Filter	200	Area	$20.00	$37.00	$200.00	$53.00
Underground Infiltration	1000	Volume	$22.00	$27.00	$50.00	$26.50
Vault	1000	Volume	$16.00	$19.00	$26.00	N/A
Wet Pond	1000	Volume	$7.50	$15.00	$73.00	$21.00

[a] Representative size provides a volume or surface area for which simple, typical, and complex costs are reported. These costs change as size changes.

[b] Costs are incremental (e.g., cost of traditional surface is subtracted from cost of LID-based surface).

2007 Analysis of International BMP Database Cost Data

Geosyntec staff analyzed the International BMP Database in 2007 for those studies that included cost information. This data were sponsored and reviewed by WERF, American Society of Civil Engineers (ASCE)-Environmental and Water Resources Institute (EWRI), EPA, Federal Highway Administration, and American Public Works Association representatives. However, much of the cost information is from dates prior to 2005, which predates much of the more mainstream applications of LID controls and, therefore, may have less representative values. The summary of cost data spreadsheet (International Stormwater BMP Database, 2007) was reviewed for information applicable to this literature review. The data contained in the spreadsheet are local project cost information and will be used to verify the cost curves that will be developed.

2.4. Quality Metrics

2.4.1. Quality Requirements for Secondary Data

Quality assurance procedures and metrics were followed for the literature review process. This section provides an assessment of the data quality contained within the literature review.

2.4.2. Procedures for Determining Quality of Secondary Data

Consistent with the EPA's QA requirements, the approved QAPP describes the procedures that facilitate selection of appropriate data and information to support the goals and objectives of this TO. Specific secondary data quality procedures discussed below include:

- Secondary data source quality
- Data selection criteria
- Hierarchy for data selection
- Data review process
- Data quality checks and procedures.

The project team recognizes that each source of data has different levels of quality assurance, and data quality may vary from source to source in ways that are difficult to quantify. Much of the data required for meeting the objectives of this TO do not allow for statistical evaluation (e.g., ranges, lack of clear description of included costs, narrative or anecdotal information). Therefore, numerical accuracy and precision evaluation may not be practical. Quality requirements associated with the data are documented based on ***Table 2-17***. Where metadata exist that describe precision, accuracy, completeness, or other uncertainty measures with respect to the data, the project team has assessed the data quality based on the confidence and accuracy of data and note this in the data ranking. In cases where no QA descriptions are available, the data have been accepted on an as-is basis, recording the respective data quality rank. Screening of data to determine selection and inclusion are based on the following characteristics:

- Current (post 2005)
- Applicable to LID cost-estimation analysis
- Technically relevant to support the evaluation objectives
- Available at a national scale or at a regional scale with appropriate adjustment factors
- Manageable in terms of complexity and maintenance for NSC use.

While not all characteristics must be met, data quality and selection is highly dependent on meeting multiple characteristics. Case studies (as available) and other documentation of LID control cost analysis have been identified to validate the ranges of costs determined with this effort. ***Table 2-16*** identifies the hierarchy of data sources in preferential order of quality, with 1 as highest quality and 4 as undergoing less peer review or appearing only in project bid tabs rather than rigorous peer-reviewed sources.

Table 2-16. Quality Hierarchy of Secondary Data Sources

Rank	Quality	Number of Characteristics	Sources
5	Highest	Contains all 5 characteristics	Independent, peer-reviewed data sources
4	Second	Contains at least 4 characteristics	Regularly cited and widely accepted data sources
3	Third	Contains at least 3 characteristics	Peer-reviewed conference proceedings, well-documented online calculators, municipal and local governmental agency final construction data sources
2	Fourth	Contains at least 2 characteristics	Non-peer reviewed conference proceedings, municipal bid tabs, and other online or literature data sources

2.5. Findings and Recommended Scientific Approach to Developing Cost Information for Stormwater Control Measure Comparisons

A review of literature indicates that stormwater control type, extent of required detail, drainage area and type of land use, development condition, and design standards all result in a wide ranges in cost information for stormwater controls. When considering the level of understanding and detail of cost considerations, one must place these needs into perspective with the level of detail included in the EPA NSC. This literature review suggests that the following factors resulted in a wide distribution of costs for a particular stormwater control:

- Project type (new development, redevelopment, retrofit)
- Need for land acquisition
- Project scale (size of LID control and area treated)
- Project purpose (e.g., demonstration project)
- Regulatory and permitting requirements
- Design requirements
- Public vs. private projects
- Flexibility in site selection
- Site suitability
- Partnerships with others (e.g., grants, cost sharing, donated time or materials)
- Level of experience of designers and contractors.

However, other notable gaps of information within the literature that make full assessment rather difficult included the level of documentation regarding what costs were accounted for in reported values. As such, simplification of cost data is necessary for the NSC to make informed decisions regarding both individual and multiple LID controls approaches. For example, costs due to land acquisition, permitting, and design for different stormwater standards should be excluded because these factors are localized and are not appropriate for inclusion in a national tool. The primary goal then is to focus cost information on those factors that most affect costs.

A review of current LID control cost and performance tools indicates that all tools use simplified unit costs based on significant cost factors (e.g., type of installation method and type of barrel material for rain harvesting). The exception to this is that some tools allow users to enter customized item costs for a more accurate cost estimate. One of the main inconsistencies between tools is the calculation and reporting of units. Some cost tools vary cost units based on type of LID control (e.g., cost per gallon for rain harvesting, but cost per impervious area managed for permeable pavement) while others use consistent units (e.g., cost per acre treated or cost per square foot of LID control built).

In addition to and perhaps as important to the empirical data reviewed in this document is the approach to adequately capture the primary site and design factors that influence LID control practice costs. Key project and site-specific variables, including whether the project is being applied as part of a new development or redevelopment, as well as site characteristics such as slope, soils, and other aspects of site preparation and design, are often dictated by the site condition. Site condition, in turn, influences cost. Another key project variable is the size of the LID control, which is dictated by the stormwater runoff generated by the impervious tributary area. A larger volume of stormwater runoff will generally require a larger and more costly LID control to treat and/or store the runoff.

It is important to note, however, that it is not necessary to account for each source of variability to meet the technical requirements of this analysis. Therefore, empirical data alone are not recommended to develop cost relationships. Rather, the project team proposes a process that develops a range of costs (Simple, Typical, and Complex) based on averages of line-item unit costs. By varying the line-item costs based on degree of implementation with necessary treatment size, volume, or flow rate estimating framework, the project team believes the approach will better represent a range of design criteria and site conditions. The following general guidelines were used to develop the simple, typical, and complex cost curves. The cost curves are believed to bracket expected costs appropriately.

- **Simple:** Design criteria are generally lower than current design practices and site conditions are conducive for BMP installation; likely representative of privately constructed and maintained BMPs in new development, on a suitable parcel of land, sited as part of an effective site design process.
- **Typical:** Design criteria are consistent with typical design practices (e.g., sizing for capture of 85% storm event or similar) found in current design manuals, and site conditions represent “median” conditions for new construction; likely representative of BMPs designed per public maintenance standards (generally more stringent) and sited as part of an effective site design process in new development or large redevelopment.
- **Complex:** Design criteria are stringent and site conditions are difficult or constrained; cost curves represent higher end estimates for all line items to meet project difficulty, may overpredict costs for many sites that do not face these difficulties or constraints. Small redevelopment projects and retrofit projects may tend toward this end of the range.

2.6. Data Analysis, Interpretation, and Management

2.6.1. Data Validation Procedures

Table 2-17 presents the ranking of the literature reviewed for this TO, as well as the evaluation of the literature based on the criteria outlined above (e.g., current, applicable, technically relevant). The data source rank and characteristic rank follows the criteria in ***Table 2-17***. The characteristics rank column represents how many of the data quality characteristics are met. For example, a source that is applicable, technically relevant, scalable to national level, post-2005, and management in terms of complexity ranks a 5. The total rank is the average of the characteristics rank and the data source rank.

It should be noted that ***Table 2-17*** includes data sources from **Section 2** and significant sources of cost data from current cost tools. Not all sources were incorporated because it was difficult to track exact sources for some current cost tools. Cost tool user's guides, methodology, and manuals were generally excluded from this table, as were specific unit cost sources such as RSMeans that make regional and temporal costs comparable.

Table 2-17. Literature Source Evaluation

Source	Data Characteristics					Charact. Rank	Data Source Rank	Average
	After 2005	Applicable	Tech. Relevant	Scale	Manage-able			
Bannerman, 2003	N	Y	Y	Y	Y	4	2	3
BES, 2000	N	Y	Y	Y	Y	4	3	3.5
BES, 2005a	Y	Y	Y	Y	Y	5	2	3.5
BES, 2005b	Y	Y	Y	Y	Y	5	2	3.5
BES, 2006	Y	N	Y	Y	Y	4	3	3.5
BES, 2008	Y	Y	Y	Y	Y	5	3	4
Brown and Schueler, 1997	N	Y	Y	Y	Y	4	4	4
City of New York, 2008	Y	Y	Y	Y	Y	5	2	3.5
FHA, 2014 (access date)	N	Y	Y	Y	Y	4	3	3.5
Green Building Alliance, 2014 (access date)	Y	Y	Y	Y	Y	5	3	4
Green Roofs for Healthy Cities, 2006	Y	Y	Y	Y	Y	5	2	3.5
GSA, 2011	Y	Y	Y	Y	Y	5	4	4.5
Hunt and Szpir, 2006	Y	Y	Y	Y	Y	5	3	4
Iowa Stormwater Partnership, 2008	Y	Y	Y	Y	Y	5	3	4
Lake Superior Streams, 2014	Y	Y	Y	Y	Y	5	2	3.5
LID Center, 2000	N	Y	Y	Y	Y	4	4	4
LID Center, 2005	Y	Y	Y	Y	Y	5	4	4.5
LID Center, 2014	Y	Y	Y	Y	Y	5	3	4
Livingston et al., 1997	N	Y	N	Y	Y	3	2	2.5
MSD, 2009	Y	Y	Y	Y	Y	5	2	3.5
MPCA, 2011	Y	Y	Y	Y	Y	5	3	4
NC-DSWC, 2006	Y	Y	Y	Y	Y	5	4	4.5

(continued)

Table 2-17. Literature Source Evaluation (continued)

Source	Data Characteristics					Charact. Rank	Data Source Rank	Average
	After 2005	Applicable	Tech. Relevant	Scale	Manage-able			
Oregon State University, 2011	Y	Y	Y	Y	Y	5	2	3.5
Peck and Kuhn, 2001	N	Y	Y	Y	Y	4	3	3.5
Pennsylvania DEP, 2006	Y	Y	Y	Y	Y	5	2	3.5
Schueler, 1987	N	Y	Y	Y	Y	4	3	3.5
SCSMC, 2008	Y	Y	Y	Y	Y	5	2	3.5
SEWRPC, 1991	Y	Y	Y	Y	Y	5	2	3.5
Sustainable City Network, 2011	Y	N	Y	Y	Y	4	3	3.5
TMRPA, 2007	Y	Y	Y	Y	Y	5	3	4
TWDB, 2005	Y	Y	Y	Y	Y	5	3	4
U.S. EPA, 1999a	N	Y	Y	Y	Y	4	4	4
U.S. EPA, 1999b	N	Y	Y	Y	Y	4	3	3.5
U.S. EPA, 2000	N	Y	Y	Y	Y	4	3	3.5
U.S. EPA, 2004	N	Y	Y	Y	Y	4	4	4
U.S. EPA, 2005	Y	Y	Y	Y	Y	5	3	4
U.S. EPA, 2013b	Y	Y	Y	Y	Y	5	4	4.5
U.S. EPA, 2014a	N	N	Y	Y	Y	3	3	3
U.S. EPA, 2014b	N	N	Y	Y	Y	3	3	3
Urban Drainage and Flood Control District, 2008								
Virginia DEQ, 2011a,2011b, 2011c, 2011d	Y	Y	Y	Y	Y	5	3	4
WEF, 2000	N	Y	Y	Y	Y	4	3	3.5
Weiss et al., 2007	Y	Y	Y	Y	Y	5	5	5
WVDEP, 2012	Y	N	Y	Y	Y	4	3	3.5
Young et al., 1996	N	Y	Y	Y	Y	4	4	4

2.6.2. Review Information Caveats

For most data, it was infeasible to determine or completely decipher how the data were gathered or all the costs that were included in the cost summaries. Moreover, the units for which costs were reported often differed. The most common units reported were cost per square foot of LID control or cost per impervious area managed. Because of the lack of information pertaining to costs, it is not possible to convert costs into consistent units. Information regarding site conditions, scale, and regulations can also contribute to the magnitude of unit costs. Additionally, the sources of the data often indicated only construction costs. Maintenance costs were usually referred to as a percentage of the capital costs or as annual or size-dependent costs. Data quality was reviewed based on source criteria to the maximum extent practicable to determine usability of data and related information.

2.6.3. Data Analysis Procedures

Data analysis included the steps listed below:

1. Quantitative and qualitative data (i.e., descriptions of major cost factors) were summarized from literature sources and costing tools.
2. Existing cost and performance tools were reviewed for additional data sources and to determine how cost data were used in each source or tool.
3. Data sources were evaluated using the data quality determination procedure described in **Section 2.3**.
4. Cost data were evaluated to identify cost trends useful for the project objectives. It was found that empirical costs must be simplified to remove confounding sources of variability.
5. Available cost data were considered in terms of the simple, typical, and complex ranges described in **Section 2.4**.

3. CRITICAL REVIEW

The literature review identified key variables that influence the cost of LID controls. Some cost variables affect the cost of all LID controls (e.g., size, design criteria, and new vs. redevelopment), while other cost variables are more specific to an individual LID control project (e.g., type of permeable pavement, type of cistern, necessity of an underdrain). The objective of this section is to provide a critical review of the variables that were identified in the literature review as variables that may significantly affect cost estimates, and to provide recommendations for the variables to be considered for inclusion in the cost component of the NSC. In the following sections, the cost variables and the cost variable evaluation criteria will be discussed.

3.1. Cost Variable Evaluation Criteria

This section will discuss the criteria by which variables that affect cost estimates will be evaluated for inclusion in the NSC. Cost variables that meet at least four of the five criteria are recommended for inclusion in the NSC. Cost variable evaluation criteria will include:

- **Feasibility** – This metric measures how easily a cost variable can be included in the NSC. The cost variables included in the NSC must be feasible to include based on the scope and budget of the project. For example, the option for user input of itemized unit costs was supported by some of the exiting tools reviewed in the literature review, however, giving users the ability to override the underlying unit costs may be less practical for the stormwater calculator due to the added complexity of this approach.
- **Resolution** – This metric examines whether or not a cost variable provides the appropriate level of accuracy and resolution for inclusion in the NSC. The NSC is a national tool and, as such, cost variables that reflect region-specific design should be avoided to the extent possible. For example, specific design criteria such as the required installation of custom outlet structures or hydrodynamic pretreatment devices may be too site- and design-specific to be recommended for support in the NSC.
- **Sensitivity** – This metric aims to include all variables that are crucial to the cost estimate by evaluating whether including or omitting the cost variable will result in substantially different cost estimates or whether the magnitude in change for a metric changes equally in application across the country. Additionally, sensitivity evaluates whether errors in estimation of the variable result in significant cost estimation errors that may negate the value of their inclusion.
- **Consistency** – For a national tool, relevant variables that are also consistently understood and applied in the same manner across all parts of the country are considered consistent, and ones that vary widely across the country are considered inconsistent and potentially more difficult to implement. For example, design requirements vary significantly across the country and are therefore not consistent.
- **Measurability** – Measurability determines if the variable represents a quantity that can be easily estimated, measured or otherwise inferred or referenced from literature sources. An example of a cost variable that could be easily estimated would be the cost of a rainwater harvesting cistern based on its size.

3.2. Evaluation of Cost Variables from Literature and Existing Tools

The literature review identified several variables as influential to LID control cost estimates. This subsection reviews these variables based on the criteria presented in the previous section. The cost variables evaluated include the following:

- **Presence or absence of pretreatment:** Pretreatment is generally used (and in some areas, required) for infiltration and filtration practices (e.g., bioretention cells, infiltration basins, permeable pavement) that are susceptible to clogging. Pretreatment can increase the life of infiltration and filtration practices by removing gross solids and sediment particles prior to entering the LID control; the tradeoff is added cost.
- **Presence or absence of reinforcement for stability (due to steep slopes):** Sites that have steep slopes must sometimes include reinforcement walls for LID controls. Swales can require check dams if the slope is such that the water will move too quickly through the swale. Other LID practices, such as bioretention, could require a wall for stability if the slopes of the side of the pond are greater than 3:1. Retaining walls or check dams add to project cost.
- **Project type (new development, redevelopment, retrofit):** One of the biggest cost factors for implementation of an LID control is whether the LID control is part of a new development project or part of a redevelopment (or retrofit) project. Often, the costs associated with redevelopment or retrofits are higher because the removal of old infrastructure and the addition of new infrastructure can be high. For example, the implementation of permeable pavement is much more expensive when existing pavement and sub-base need to be removed and hauled away before installing the new base course and permeable layer.
- **Need for land acquisition:** The need to acquire land for an LID control can be common, especially for municipalities looking to implement LID controls. The cost for land acquisition can be quite high; however, this cost is very site-specific, and cost data for land acquisition on a national scale is generally lacking.
- **Project scale:** Project scale refers to the size of the project. Because economies of scale may apply to the implementation of LID controls, larger projects will often have a smaller unit cost than smaller projects.
- **Project purpose (e.g., demonstration project)**: Project purpose is an important factor that applies to only some types of LID controls. For example, green roofs that are for “demonstration” purposes (e.g., visitors are allowed to enjoy the green roof) will be more elaborate and more costly than green roofs for practical purposes where simpler vegetation is used. Similarly, a rainwater harvesting system where the water is to be used inside for non-potable or potable uses will require the water to be treated to a greater degree than if the water were to be used outside for non-potable purposes such as watering a lawn. The indoor use project will have a higher cost due to greater water treatment requirements.
- **Regulatory and permitting requirements:** Some municipalities or regional watershed may require fees or permits for the construction or operation of LID controls. These fees are administered on a site or state basis rather than a national basis. As such, these fee requirements are difficult to include in a national tool, but they may be added on a case-by-case basis by the user.
- **Design requirements:** Design requirements refer to design specifications or standards that are put forth by a governing agency. Examples of design requirements may be the use of a specific volume of capture; type or specification of bioretention soil mixture; or specific type of

pretreatment device to meet regulatory requirements. Design requirements vary across the country.

- **Public vs. private projects:** Implementation of LID controls by public entities on private property may result in extra costs due to an increased level of service required, or the need to purchase easements; however, this scenario is relatively rare.
- **Site suitability:** Site suitability accounts for many factors, including the soil type, site slope, availability of existing infrastructure, etc. A site may be considered more suitable if there is an existing depression for an infiltration basin or a gradual slope suitable for a swale, for example, because these sites will require less excavation and hauling and other expensive site modifications to accommodate the LID control.
- **Partnerships with others (e.g., grants, cost sharing, donated time or materials):** Partnerships with others (e.g. grants, cost sharing, donated time or materials) may reduce the overall project cost for implementation of an LID control. Although these partnerships, and the resulting cost savings, may have a significant effect on total project cost, they are site specific and not applicable on a national scale.
- **Level of experience of designers and contractors:** Designers and contractors with a high level of experience may charge more money than other contractors to implement an LID control, thereby raising project costs. This cost factor varies with each project.

Each cost variable was evaluated in terms of the criteria described in **Section 3.1**. ***Table 3-1*** was created to identify which cost variables fit the criteria for inclusion in the NSC. Cost variables that do not include at least four criteria may not be recommended for inclusion in the NSC at this time, but may be recommended for future inclusion as the NSC evolves and more data becomes available.

Table 3-1. Variables to be Included in the NSC

Cost Variable	Feasibility	Resolution	Sensitivity	Consistency	Measurability
Presence or absence of pretreatment	•	•	•	•	•
Presence or absence of reinforcement for stability	•		•		
Project Type (new development, redevelopment, retrofit)	•	•	•	•	•
Need for land acquisition			•		•
Project scale	•	•	•	•	•
Project purpose (e.g., demonstration project)	•	•	•		
Regulatory and permitting requirements			•		
Design requirements			•		•
Public vs. Private projects			•		•
Site suitability (slopes, existing soil, etc.)	•	•	•		•
Partnerships with others			•		
Level of experience of designers and contractors			•		

3.3. Cost Variable Support Recommendations

In summary, four cost variables were recommended for inclusion in the NSC cost tool due to the feasibility, resolution, sensitivity, consistency, and measurability of each variable. Cost variables such as the presence and absence of pretreatment; project type; project scale; site characteristics; and suitability are all variables that meet four or more of the evaluation criteria. These variables can have a greater impact on project costs and are relatively easy to include as key cost variables within the NSC. These variables are also appropriate for a national-scale tool and have sufficient cost data available to support inclusion. ***Table 3-2*** shows the variables that are recommended for inclusion in the NSC and the justification for inclusion.

Table 3-2. Summary of Cost Variables for Recommended for Inclusion in NSC

Cost Variable	Comments
Presence or absence of pretreatment	Plays a large role in cost, availability of cost data, common design variable
Project type (e.g., new development, redevelopment, retrofit)	One of the largest factors influencing cost; typically known, even at planning stages of project
Project scale	Large factor influencing cost
Site characteristics and suitability (e.g., slope, required reinforcement for stability)	Plays a large role in cost, greatly affects site design

The cost variable “presence or absence of pretreatment” met all four criteria and is recommended for inclusion in the NSC. It should be noted that pretreatment is not a mandatory requirement for any of the LID controls included in the NSC, but pretreatment is an important consideration for LID controls such as bioretention, infiltration basins, and permeable pavement if a project elects to include pretreatment. Pretreatment also meets the resolution criteria because the presence or absence of pretreatment is easily determined at the planning stage of LID implementation. The available pretreatment options are consistently applied to LID controls. Pretreatment is also a large cost factor that should be considered in planning-level cost estimates; thus, it meets the criteria for sensitivity. Last, pretreatment meets the measurability criteria because there are cost data available that can be averaged on a national basis to determine the cost of including pretreatment.

Often the more significant cost factor for implementation of LID controls is whether the LID control is part of a new development project or part of a redevelopment (or retrofit) project. This factor is included in the variable “project type,” which is recommended for inclusion in the NSC. Retrofit projects are not always more expensive if some existing infrastructure can be reused. However, it may be difficult to use the existing infrastructure because of sizing or location issues with the newly planned development or if newer stormwater runoff standards must be met with the project. Often, the costs associated with removal of old infrastructure and the addition of new infrastructure can be higher when compared to new development. For green roofs, including a green roof in the initial building design allows for design and construction of the additional loading requirements. Retrofitting a building with a green roof when structural modifications must be made to accommodate the additional loading can be a significant investment (Peck and Kuhn, 2001). Additionally, there is a consistent effect on the costs of projects nationwide making this cost variable appropriate for this tool. The only criterion where project type is lacking the required information is measurability. It is often difficult to know the amount that inclusion of stormwater management in a redevelopment project might increase (or decrease) the total costs during the planning phases, but there are enough data to determine a nationwide incremental and comparative cost differential.

“Project scale” describes the size (i.e., how large or small) of a project; it is the most significant cost factor and is recommended as a required cost variable. In general, larger projects will cost more than smaller projects, but the unit cost of the large project is often smaller due to economies of scale. All cost variable metrics (i.e., feasibility, resolution, sensitivity, consistency, and measurability) are met with project scale. Project scale (e.g., size of drainage area treated, size of treatment practice) is already a calculated output from the NSC; therefore, it is an easy variable to include as a means of estimating stormwater costs.

“Site characteristics and suitability” is a composite variable that includes several factors such as soil characteristics, clearing and grubbing, tree removal, grading requirements, excavation and hauling needs, slope protection, and even elements of reinforcement for slope or site stability. These characteristics can have a large impact on project costs because they affect excavation, soil modification, and new infrastructure. The amounts of some of these cost components are captured in project scale because they are often related also to the size of the LID control, but there is a need to include and quantify these components in a generalized sense so that these elements of LID implementation are represented in the cost estimates. Due to the amount of data that are required to represent all site suitability elements, the current efforts aggregate these into a single cost item. Greater refinement of these elements can be completed in later updates to the NSC as more resources become available.

Table 3-3 shows the variables that are not recommended for inclusion in the NSC, as well as comments indicating the reasons behind exclusion.

Table 3-3. Summary of Cost Variables Recommended for Exclusion from NSC

Cost Variable	Comments
Presence or absence of reinforcement for stability	Plays a large role in cost, availability of cost data, and common design variable; can be included in consideration of simple, typical, or complex cost categories for site suitability information.
Need for land acquisition	Site-specific, lack of estimation process for local land cost data, easy to quantify; however, land prices change based on many variables
Project purpose (e.g., demonstration project)	No consistent means of estimating local cost data
Regulatory and permitting requirements	Site-specific, lack of cost data impacts with variations in local to state regulatory requirements, ever-changing and evolving, and reflected in design requirement changes
Design requirements	Often site-specific, relevant design requirements inherently captured as inputs to the sizing components of the NSC and, therefore, LID control size is a usable surrogate
Public vs. Private projects	Site-specific, difficult to quantify cost differences
Partnerships with others	Site-specific with much variability, difficult to quantify cost
Level of experience of designers and contractors	Site-specific, can be a large cost factor but difficult to quantify differences in cost estimation

Cost variables such as the need for land acquisition, the use of reinforcement for stability, regulatory and permitting requirements, design requirements, public vs. private projects, partnerships with others, and the level of experience of designers and contractors are dependent upon many local factors, including local knowledge and experience, as well as information on probable design and site characteristics. These factors are difficult or even inappropriate to include in a planning tool such as the NSC. These cost variables are all quite sensitive in that their inclusion in a project might have a larger proportional effect on project cost. However, these cost variables do not meet the criteria for feasibility, resolution, consistency, or measurability. Accounting for these dynamic and site-specific costs is not practical because there is no consistency between project locations, scales, and funding sources that would appropriately account for most of these cost variables. Although the project team acknowledges that these cost variables can impact final project costs, the cost variables cannot be included on a consistent basis to be used nationally for cost estimation, justifying their exclusion from the NSC.

3.4. Key Tools and Methods

The literature review identified key cost estimation variables from literature sources and cost tools and proposed criteria and metrics to assess relevant cost information for stormwater control measure comparisons based on simple, typical, and complex design cost curves. The objective of this section is to provide a critical review of the recommended approaches based on existing tools and related approaches to assess the site suitability, ease of implementation, and maintainability of the tool components relative to what might go into the NSC.

3.4.1. Criteria for Evaluating Tools and Method Approaches

To provide an objective critical review of the key tools and methods identified during the literature search, as well as the recommended approach based on the use of cost curves, this section summarizes a set of review criteria determined to be most relevant to the implementation and use of the NSC. The review criteria to be applied are described as follows:

- **Features and benefits** – Ultimately, the features and benefits of the cost component of the NSC should include as many of the desirable and user-defined features and benefits found in existing tools as can be delivered within the budget and scope of the project. These features include support of all the LID controls that are currently supported by the NSC; support for various types of cost such as capital, and maintenance and operating costs; reasonable accuracy; the ability to show variability in costs; and presentation of results in units that are relevant to the user and suitable for each LID control. Benefits to the user include the ability to obtain representative cost estimates that account for the variables at their site, with minimal input requirements. Specific features and benefits included as part of the evaluation criteria are discussed as follows:
  - <u>Accuracy and support for cost variability</u> – LID control implementation costs are inherently variable due to the sheer number of factors that affect costs. For this reason, methods that display a range of costs or provide some indication of the variability of costs are preferred. Methods that match the accuracy of the other computations in the NSC are also preferred and having the option to increase the accuracy of cost estimates with additional input such as unit costs is considered a plus.
  - <u>Support for capital, maintenance and lifecycle costs</u> – Methods that support the various costs that comprise the entire life cycle cost of an LID control are recommended for inclusion in cost estimation (however, benefit cost analysis raises complex issues).
  - <u>Ease of use</u> – Methods that provide reasonable estimates with minimal user input requirements should be selected. Inputs that are readily available, easily measured, or computed are more desirable. This criterion could conflict with the accuracy criterion, depending on implementation; therefore, a balance between accuracy and ease of use is required.
  - <u>Uniformity of application to all supported LID controls</u> – Methods that are consistent in their support and applicability to all the LID controls currently supported by the NSC are preferable. Approaches that include cost estimation computations that are uniformly applicable to multiple LID controls are easier to explain and communicate to users.
  - <u>Presentation of results in relevant units</u> – Methods that result in the presentation of cost estimates in units that are most readily accessible to the user are considered desirable.

- **Ease of implementation** – Given the realities of project schedules and budgets, a method that is easy to understand and communicates to programmers for implementation in the existing NSC is desirable.
- **Maintainability and ease of updates** – Because BMP design and construction evolves and cost data changes over time, the ability to easily update a method and/or the underlying data that are used by the method to improve estimates is considered desirable.

3.4.2. Critical Review of Proposed Approach

The project team proposes a process that develops a range of costs (i.e., Low, Typical, and High) based on line item unit costs and typical ranges of aggregated variables. By varying the line item costs based on the degree of implementation with necessary treatment size (i.e., based on volume, or flow rate capacity estimates), costs can be computed and plotted on cost curves to be used as the basis for cost estimation. The Project Team believes this approach will better represent a range of design criteria and site conditions. The following general guidelines are proposed for the development of the simple, typical, and complex cost curves:

- **Simple** – Design criteria are generally lower than current design practices, and site conditions are conducive for BMP installation; likely representative of privately constructed and maintained BMPs in new development, on a suitable parcel of land, sited as part of an effective site design process.
- **Typical** – Design criteria are consistent with typical design practices (e.g., sizing for capture of 85% storm event or similar) found in current design manuals, and site conditions represent "median" conditions for new construction; likely representative of BMPs designed per public maintenance standards (generally more stringent) and sited as part of an effective site design process in new development or large redevelopment.
- **Complex** – Design criteria are stringent and site conditions are difficult or constrained; cost curves represent higher end estimates for all line items to meet project difficulty; may overpredict costs for many sites that do not face these difficulties or constraints. Small redevelopment projects and retrofit projects may tend toward this end of the range.

3.4.3. Features and Benefits

The primary features and benefits of a successful approach lie in its inherent simplicity and focus on the tangible aspects of the cost estimation process:

- **Accuracy and support for cost variability** – The recommended cost curve approach inherently supports variability by using simple, typical, and complex design cost curves as the basis for cost estimates. The accuracy of the method can be increased or decreased by simply including more or fewer line items in the underlying itemized costs that are used to develop the curves and, therefore, ranks high in terms of suitable accuracy and support for communication cost variability to users.
- **Support for capital, maintenance, and lifecycle costs** – The recommended cost curve approach can be implemented with separate curves for capital, maintenance, and life cycle costs, thereby providing full support for capital, maintenance, and lifecycle costs.
- **Ease of use** – The cost curve approach is transparent to the user and can easily be implemented in a way that makes it easy to use and explain to others. The approach can be implemented in ways that require as few user inputs as are needed to read values from a curve and apply them. This is typically on the order of a handful of inputs per cost estimate, depending on how the cost curves are structured and how many adjustment factors are included in the implementation. On the other

hand, a fair amount of cost data needs to be maintained to support the itemized unit costs from which the curves themselves are generated.

- **Uniformity of application to all supported LID controls** – The cost curve approach can be uniformly applied to all LID controls. Since the curves will be developed from unit costs, all the LID controls that are currently supported by the NSC can be supported, and uniformity can be enhanced by including similar unit cost line items in the cost estimation framework that will be used to generate the cost curves whenever possible. Cost curves are easy to explain and communicate to users and are applied to all LID controls in the same manner, regardless of whether the LID controls are volume limited, flow limited, or both.
- **Presentation of results in relevant units** – Independent of the units of the cost curves themselves, cost estimates generated from the curves can be presented in various units, including cost per unit of LID control footprint area, cost per LID control volume, or cost per LID tributary area treated.

3.4.4. Ease of implementation

Ease of implementation provides information on whether the cost curve approach can be uniformly implemented for all LID controls. The curves themselves are an abstraction that hides the details of the underlying unit costs, which necessarily vary by LID control type. The cost curve approach is likely to support the use of the same or similar code base for all LID controls.

3.4.5. Maintainability and Ease of Updates

All the other criteria previously discussed have implications on the maintainability of the cost curve approach. The cost curve approach limits required user inputs; however, the tradeoff for limited input data is the amount of information that has to be maintained to support the generation of the curves. In this regard, the cost curve approach may be more difficult to maintain and somewhat harder to update than other methods. Recommendations for easing the maintenance burden are to limit the itemized cost items to a small set of the most influential cost variables, as identified in **Section 2**.

3.5. Review of Existing Tools

Section 3.3 of this report recommended cost variables to be used in the NSC based on evaluation of each cost variable using the criteria of feasibility, resolution, sensitivity, consistency, and measurability. In this section, the cost variables recommended for inclusion in the NSC were compared to the breadth of cost variable support found in existing tools. ***Table 3-4*** provides a summary of how the cost variables identified in **Section 3.3** for inclusion in the NSC are used by the existing cost tools.

Table 3-4. Existing Cost Tools and Effects of Key Cost Variables

Tool	Inclusion of Key Cost Variables	Tool Evaluation and Comments
WERF Whole-Life Cost Tool	Pretreatment, project type, and site suitability are not separated. Unit costs are averaged based on key variables, which vary based on LID control type.	Key cost variables are unique for each LID control. For rain gardens, the major cost variable is self vs. professional installation. A unit cost determined by self or professional installation is multiplied by size to find the cost of the rain garden.
CNT Green Values™	This online tool uses unitized costs to determine life cycle costs. Unit costs are available as low, mid, and high estimates. Pretreatment is not a component, neither is project type. It is unclear if site suitability is taken into account.	No transparency to determine key cost variables. The tool uses cost information from municipalities, public utilities, and research projects. Costs are then averaged over the size of the LID control and used to calculate costs on a square footage basis.
SUSTAIN	SUSTAIN uses unit costs derived from itemized cost estimates. Customized costs can be added, but this is a separate input file, and it is unclear how these might change tool calculations and results.	Not enough transparency to determine key cost variables. For example, not enough transparency in the data to determine the extent to which pretreatment, project type, and site suitability were considered.
SBPAT	Cost estimation was based on regression equations found in literature and unit construction costs. Costs were normalized to per acre treated. Impact of pretreatment, project type, and site suitability were not included; however, adjustment factors are exposed for users to adjust cost estimates to account for these factors.	Project scale. Although costs are reported as cost per acre treated with no transparency with regard to project type or site suitability, unit costs depend upon if the LID control is distributed (1-10 acre catchment) or regional 100 acre catchment).
BMP REALCOST	Costs equations were developed using cost estimates from a Denver engineering firm. Separation of the effects of pretreatment, project type, and site suitability are not possible.	Key variables could not be identified. Users are presented costs based on a parametric equation or by manually entering a unit cost.

Table 3-4 indicates that all of the existing cost tools provide differing levels of transparency about the effects of pretreatment, project type, and site characteristics on project cost. Although four of the five tools do allow for user-entered costs (which would allow a user to account for the costs associated with these variables), these tools would be improved by making the costs more obvious and transparent to users so that users may see the impact these variables have on project costs.

The WERF Whole-Life Cost tool offers users cost of LID controls generally based on fewer than five user inputs. For example, the cost estimate generated for green roofs relies on five categories: roof area, building height, roof function (see project purpose variable in **Section 2**), the need for irrigation, and the level of maintenance. Project purpose was excluded as a recommended NSC cost variable because there is no consistent means to estimate local data. Additionally, the cost variables chosen for inclusion in the NSC apply to multiple or all LID controls, whereas the WERF cost tool approaches the major cost variable as being individual to each LID control. The variables for rain garden are drainage area, garden area, installation method (self or volunteer), single house or neighborhood installation, and level of maintenance. The cost of permeable pavement, on the other hand, is based almost solely on the type of permeable pavement system being implemented. We believe level of maintenance is a useful variable to include. Variations between types of permeable pavement may be captured in the complex versus simple aspects of the cost approach that we recommend.

The CNT Green Values™ tool uses unit costs derived from cost estimates collected from literature, as well as from municipalities, public utilities, and research projects. Unit costs (usually as $/square foot of LID control) are reported as low, middle, or high in the calculator database. The CNT tool uses the middle cost in each case. Therefore, the key variables used for this tool are not identifiable and thus cannot be compared to recommended cost variables discussed in **Section 2**. We do believe that providing the range of possibilities along with a range of project costs is an effective way of communicating the potential variability in costs.

The other tools, including SUSTAIN, SBPAT, and BMP REALCOST, have less transparency on the key deterministic cost variables and how they compare to those recommended for the NSC. Resource limitations prevent a deeper exploration of the key variables and how they are applied in these tools However, several factors, such as the idea of optimization and the application of least cost curves, are intriguing and are worth further investigation.

3.6. Lessons Learned from Critical Review of Recommended Approach

A critical review of the proposed cost curve approach reveals a number of recommendations to guide the implementation of the approach and to ensure that the approach improves on key existing tools and methods in terms of features and benefits, as well as ease of implementation and maintainability. A summary of the recommendations from the critical review are presented as follows:

- Given the resolution and accuracy of other quantities calculated by the NSC, it is prudent to inform users that cost estimates are planning-level estimates only. Letting users know that the default cost estimates are rough and then giving more experienced users a way to improve the default estimates with additional input such as unit costs and quantities specific for their area and site would provide the ideal balance between accuracy and complexity.
- Given the variability of design and implementation costs, it makes sense to provide cost estimates as ranges rather than single quantities. Ranges are a simple way to communicate the inherent variability and uncertainty in the estimates to lay users. The recommended approach is well-suited for providing ranges as outputs based on cost curves for simple, typical, and complex design criteria.
- One of the primary motivations for estimating planning-level cost estimates is to compare the cost of alternative LID implementations. Different conclusions regarding the most cost-effective alternative may be reached, depending on whether one is looking at capital costs only or whether operating and maintenance (O&M) costs are included. Lifecycle costs that include separate capital and O&M cost components that are reported as separate quantities gives users a more complete understanding of the cost of alternatives.
- For a national tool, the ability to present the results of cost estimates in multiple units or allowing users to select and change the units of the estimates could potentially save users time and make the tool more useful to a wider audience.
- Supporting cost variables such as the presence or absence of pretreatment, and accounting for project type and site suitability in a manner that is transparent to users would be an improvement over most of the key existing tools reviewed.

3.7. Findings and Recommendations for Developing Cost Estimation Component for NSC

The recommended approach for the implementation of the costs in the NSC is based on developing and applying representative cost curves. As outlined in **Section 2.4**, a range of cost curves that will bracket simple, typical, and complex design costs is recommended. Costs can be reported to the user as a range of costs that fall within the simple and complex cost curves, rather than a single value. Providing the users of the NSC with a range rather than a single cost value better reflects the uncertainty of the cost estimate.

Two major components that influence successful implementation include the key site variables that should be accounted for, and the features and benefits that must be supported to enable the NSC achieve parity with, or improve on, existing tools and methods. As discussed in **Section 3.3**, the key variables that are recommended for inclusion in the NSC are as follows:

- Presence or absence of pretreatment
- Project type (new development, redevelopment, retrofit)
- Project scale, and
- Site suitability.

These variables are recommended because they met at least four of five criteria outlined in **Section 3.2**. Additional variables may be included in the NSC in the future as desired based on data availability, calculator feedback, and resources. The variables that are envisioned for the NSC will help the user to plan LID control cost implementation and to understand how the estimated costs compare to the simple, typical, or complex range of the cost curves. Ideally, NSC users could be given control over these variables through an interface that allows users to refine cost estimates based on cost relevant (e.g., deterministic) variables. ***Table 3-5*** summarizes potential approaches for applying cost variables in the NSC and provides implications of inclusion of each cost variable.

Table 3-5. Summary of Methods for Including Cost Variables into the NSC

Variable	How to Include Into the NSC	General Result
Pretreatment	Binary selection mechanism such as checkbox to indicate presence or absence of pretreatment	Pretreatment results in a typical or high design cost based on typical to complex cost curves
Project Type	Multiple option, single choice mechanism to indicate project type such as new development, re-development, or retrofit	New development may result in simple or typical cost, but re-development or retrofit would result in typical to complex costs
Project Scale	This could be accounted for by the calculated size of the LID facility	A larger LID control will have a larger overall cost but a lower unit cost due to economies of scale
Site Suitability	Multiple option, single choice mechanism to indicate site suitability such as ideally suited, moderately suited, poorly suited	Ideally suited may result in lower cost, poorly suited may result in higher cost

The potential methods for incorporating the cost variables into the NSC as presented in ***Table 3-5*** communicate the intent, and discuss in general terms, how the variables may be included within in the NSC. The techniques discussed are intentionally presented in general terms in order to not prematurely exclude other equally viable approaches at the early stages of planning. How to incorporate these techniques was further refined and completed in Task 4 (**Section 4**), along with other implementation details. As an example, cost variable checkboxes and subsequent combining of costs to appropriately account for the majority of identified cost variables were explored. If a user checks a “no pretreatment,” a "new development" box, and "ideally suited" checkboxes, the costs presented to the user could apply the simple cost curve as a minimum value with possibilities of increasing the range of costs depending on other checked boxes. If a user indicates that "pretreatment" is required, the site is a "re-development" location, and is also "poorly suited" for LID infiltration measures, the range of costs presented to the user may be much higher and likely closer to the maximum value associated with the high cost curve. A drawback of this approach is that it is possible to have atypical scenarios for which the NSC cost tool may find it very difficult to provide costs. For example, an LID control with pretreatment that might fall into the "low" cost category may not account other site factors, such as the ability to use existing infrastructure, or a partnership with a land owner where land may be donated. Such specific scenarios are not feasible to include in the NSC. However, the checkbox approach seems the most appropriate for level of understanding and complexity of implementation of these cost variables based on the detail of other inputs of the NSC. This was a critical component for determining an approach to implement the cost variables that included transparency for users and also provides a level of resolution commensurate with the current NSC LID water quantity and treatment estimates.

In addition to the cost variables supported, there are other key features and benefits that may be relevant to potential users. The Project Team's recommendations for these other features and benefits are as follows:

- Support for separate cost estimates for capital and maintenance costs. Users can then calculate life cycle costs based on an assumed life span using the capital and maintenance costs. Life cycle costs are a typical and desirable approach for comparing various LID implementation scenarios.
- Support for multiple normalized cost units whereby users can easily select alternate units. Recommended units and methods of normalization include
  - Cost per surface area of LID control
  - Cost per tributary area treated
  - Cost per unit flow treated
  - Cost per unit volume treated
  - Cost per unit volume of LID control
- Exposure of cost adjustment factors for user manipulation. This may include
  - Retrofit adjustment factors
  - Engineering, permitting, and contingency factors
  - Inflation adjustment factors
  - Regional cost index factors

As with any tool, longevity, frequency, and flexibility and ease of updates are a concern because they require resources and maintenance to keep the tool relevant for users. Therefore, the approach for NSC cost estimation development should consider how to ease information maintenance and updates. The cost curve approach simplifies cost estimation conceptually by reducing the complexities related to analysis that would be required when computing unit costs. Once the curves are created, it becomes inconsequential to estimate LID control implementation costs. Conceptually separating the creation of the curves from the use of the curves in the NSC insulates the NSC from changes to the underlying cost data since the NSC only depends on the curves themselves. This separation also makes it easier for EPA to complete data maintenance. If properly implemented, the cost component of the NSC can support dynamic updates of curves without requiring updates within the rest of the application if curves are ingested from an external source such as a flat file.

4. COST ESTIMATION PROCEDURE SELECTION AND DEVELOPMENT

The cost estimation procedure was developed by evaluating the input parameters to the NSC to determine the type of information and limits of user inputs supported by the tool. Next, these variables were evaluated to determine how critical and influential unit cost items might be incorporated into costs estimates that accurately reflect changes in those design variables. For those critical items in which there was not an existing design variable within the calculator, these were added as selectable options. Based on user input for select variables (soils, slope, and added variables such as pretreatment and site suitability), three design scenarios (simple, typical, and complex) were assigned for the scenario the user is evaluating. Using the influential design variables and known properties of the LID controls, cost curves were developed using nationally available unit cost estimates from literature and were adjusted to 2014 dollars using RSMeans (www.rsmeans.com), a database of verified costs for construction materials, labor, and equipment. An automated Microsoft Excel spreadsheet with a simple macro was programmed and then applied to incrementally calculate various sizes of LID controls into the unit cost estimation tables in the spreadsheet to obtain capital costs that will plot on curves. A brief summary of the above implementation steps are provided below:

- Step 1 – Define NSC user input limits and allowable LID control size variable limits,
- Step 2 – Record design variables for LID controls, including NSC defaults for each variable, and eliminate variables that do not significantly affect cost estimates,
- Step 3 – Define simple, typical, and complex values for remaining variables that are influential for costs,
- Step 4 – Develop line-item costs for variables that are considered significant,
- Step 5 – Use an automated Excel spreadsheet to repeatedly size to estimate costs for all LID controls under all three design scenarios to produce cost curves.

The cost estimation procedure is based on the use of cost curves and is similar to the complexity and ease of use of the NSC. The cost curves were developed from unit costs for various sizes of LID controls used within the NSC. Cost curves were developed for three design scenarios (simple, typical, and complex) for each LID control by varying the quantities of unit costs and other cost items commensurate with the intricacy of implementation, LID control design parameters, and site feasibility constraints. The Project Team believes this is a more robust and representative approach to characterize the range of design criteria, site conditions, and variations expected for a nationally applicable tool.

4.1. Defining NSC User Input Limits and Allowable LID Control Size Limits

The current version of the NSC (1.1.0.0) sets upper and lower bounds on user inputs and limits users to entering quantities within those bounds. The implementation of the cost estimation approach began with the evaluation of the NSC to determine the design variables and limits of user inputs for key cost variables. This allowed the project team to set upper and lower limits of the anticipated sizes of LID controls based on the data input limits in the NSC and to ensure that adequate cost information is provided for the range of supported user inputs. For instance, we determined that the smallest allowable LID Practice footprint in the NSC is 4.4 square feet (ft^2). The other limits are shown in ***Table 4-1***.

Table 4-1. NSC User Input Limits on Key Cost Variables

Input Variable	Limit
Smallest study area supported (A_{trib})	0.1 acres
Smallest LID control implementation ratio (I)	1%
Smallest LID practice footprint ratio (% capture ratio) (F)	1%
Implied smallest supported LID practice footprint area (A_{LID})	$A_{LID} = A_{trib}$ x I x F = 4.4 ft^2
Smallest cistern storage size support	25 gallons
Largest study area supported (A_{trib})	500 acres
Largest LID practice implementation ratio (I)	100%
Largest LID practice footprint ratio (% capture ratio) (F)	100%
Implied largest supported LID practice footprint area (A_{LID})	$A_{LID} = A_{trib}$ x I x F = 21.78 million ft^2
Largest cistern storage size supported (size x number of cisterns)	550,000 gallons

With the exception of the cisterns used for rainwater harvesting, all the supported LID controls have sizes that are best quantified in units of area and are therefore subject to the footprint area limits shown in ***Table 4-1***. Cistern size limits are presented on separate lines because they are in units of gallons of storage.

4.2. LID Control Variables Supported by the NSC and Influential for Cost Estimation

The NSC supports various sizing variables for each supported LID control. The quantities provided by NSC users for some of these variables directly affect the quantities that are used in the itemized cost estimates. ***Table 4-2*** shows all the variables that are exposed to users for each of the supported LID controls, along with default values (note that vegetated swales are currently not supported in the current version of the NSC). Variables that change the footprint of LID controls, or the quantities of the materials used for construction, will affect itemized costs. Design variables that affect cost estimation quantities are noted in the table. Three sets of values are defined in **Section 4.3** for each of these variables.

Table 4-2. NSC LID Control Design Variable User Input Default Values

Variables	Impervious Area Disconnect	Rainwater Harvesting	Rain Garden	Green Roof	Street Planter	Infiltration Basin	Permeable Pavement
Footprint Ratio (% Capture Ratio)[a]	100	—	5	—	6	5	100
Cistern Size (gal)[a]	—	100	—	—	—	—	—
Emptying Rate (gal/day)	—	50	—	—	—	—	—
Number per 1,000 ft^2 [a]	—	4	—	—	—	—	—
Ponding Height (in)	—	—	6	—	6	—	—
Soil Media Thickness (in)[a]	—	—	12	4	18	—	—
Soil Media Conductivity (in/hr)	—	—	10	10	10	—	—

(continued)

Table 4-2. NSC LID Control Design Variable User Input Default Values (continued)

Variables	Impervious Area Disconnect	Rainwater Harvesting	Rain Garden	Green Roof	Street Planter	Infiltration Basin	Permeable Pavement
Gravel Bed Thickness (in)[a]	—	—	—	—	12	—	18
Basin Depth (in)[a]	—	—	—	—	—	6	—
Pavement Thickness (in)[a]	—	—	—	—	—	—	6
Total number of input variables	**1**	**3**	**4**	**2**	**5**	**2**	**3**

[a] This design variable affects itemized costs quantities.

The ten user input variables shown in ***Table 4-2*** (left column) were used as the basis for defining line items for unit cost estimates. For each of the design variables that affect costs, one or more corresponding line items were included to account for the effect of that design variable. Other line items were added to the cost estimates that are not directly related to the size of the LID control but are necessary to account for other activities, design features, and processes necessary for construction such as mobilization. ***Table 4-3*** shows the line items for cost estimation.

Table 4-3. Line Items for Cost Estimation

Cost Item	Units	Cost	Source / Reference
Mobilization	EA	$1,500.00	RSMeans 2014 Quarter 4
Demolition	%	$5.00	Engineer's Opinion of Probable Construction Cost for Project
Clearing & Grubbing	ft^2	$0.18	RSMeans 2014 Quarter 4
Dewatering	DAY	$162.50	RSMeans 2014 Quarter 4
Embankment	ft^3	$0.37	RSMeans 2014 Quarter 4
Excavation (0 – 1,000)	ft^3	$0.07	RSMeans 2014 Quarter 4
Excavation (1,000 – 10,000)	ft^3	$0.06	RSMeans 2014 Quarter 4
Excavation (10,000+)	ft^3	$0.23	RSMeans 2014 Quarter 4
Haul/Dispose of Ex Material	ft^3	$0.37	RSMeans 2014 Quarter 4
Finish Grading	ft^2	$0.03	RSMeans 2014 Quarter 4
Soil Media / Planting Media	ft^3	$2.10	RSMeans 2014 Quarter 4
Pea Gravel	ft^3	$1.39	RSMeans 2014 Quarter 4
Gravel	ft^3	$1.22	RSMeans 2014 Quarter 4
Gravel fill 3/4"	ft^3	$1.22	RSMeans 2014 Quarter 4
Base Course Gravel	ft^3	$0.39	RSMeans 2014 Quarter 4
Pavement	ft^2	$3.18	CNT Stormwater Toolbox
Mulch	ft^3	$0.30	RSMeans 2014 Quarter 4
Vegetation – Simple	ft^2	$0.25	Engineer's Opinion of Probable Construction Cost
Vegetation – Typical	ft^2	$1.20	Engineer's Opinion of Probable Construction Cost
Vegetation – Complex	ft^2	$2.33	Engineer's Opinion of Probable Construction Cost

(continued)

Table 4-3. Line Items for Cost Estimation (continued)

Cost Item	Units	Cost	Source / Reference
Slotted PVC Underdrain Pipe	LF	$11.90	RSMeans 2014 Quarter 4
Hydroseed	ft^2	$0.65	RSMeans 2014 Quarter 4
Soil de-compaction 4–6"	ft^2	$0.40	Engineer's Opinion of Probable Construction Cost
Soil de-compaction 6–8"	ft^2	$0.60	Engineer's Opinion of Probable Construction Cost
Impervious area removal	ft^2	$1.62	RSMeans 2014 Quarter 4
Roof downspout disconnection	EA	$9.77	RSMeans 2014 Quarter 4
Cistern inlet structure	EA	$20.00	Engineer's Opinion of Probable Construction Cost
Cistern outlet structure	EA	$20.00	Engineer's Opinion of Probable Construction Cost
Cistern overflow structure	EA	$20.00	Engineer's Opinion of Probable Construction Cost
Inflow Structure(s)	EA	$1,240.00	RSMeans 2014 Quarter 4
Outflow Structure(s)	EA	$1,240.00	RSMeans 2014 Quarter 4
Overflow Structures(s)	EA	$1,240.00	RSMeans 2014 Quarter 4
Cistern/Storage Tank(s) – Simple	GAL	$0.37	http://tankulator.ata.org.au/tank-materials-price-comparision.php (Accessed Feb 2015)
Cistern/Storage Tank(s) – Typ.	GAL	$0.68	http://tankulator.ata.org.au/tank-materials-price-comparision.php (Accessed Feb 2015)
Cistern/Storage Tank(s) – Complex	GAL	$0.91	http://tankulator.ata.org.au/tank-materials-price-comparision.php (Accessed Feb 2015)
Perimeter fence	LF	$4.80	RSMeans 2014 Quarter 4
Engineering	%	$10.00	Project Construction Bid Tab
Contingency – Simple	%	$2.00	Project Construction Bid Tab
Contingency – Typical	%	$10.00	Project Construction Bid Tab
Contingency – Complex	%	$15.00	Project Construction Bid Tab

It should be noted that the intent of the cost data and estimation procedure is to produce general estimates for relative comparisons of LID control alternatives. Therefore, line items implying a greater level of accuracy than implied by the datasets used in stormwater quantity and LID control sizing in the NSC were intentionally excluded. For example, cost items such as engineering and permitting costs, sales tax, construction inspection, land acquisition costs, geotechnical investigations, and surveying are not feasible for inclusion in the cost estimation procedure because the NSC does not include enough information to support the estimation of these cost items. Also, these costs are typically applied as percentage factors in detailed cost estimation efforts rather than planning-level cost estimates. Projects where the impact of omitting these costs is deemed significant can simply apply an additional contingency factor that represents the combined total of the omitted line items. It is expected that in most cases, planning-level estimates are sufficient for users of the NSC to evaluate LID control alternatives based on relative cost differences of various LID controls as estimated using this procedure.

In addition to the unit costs shown in ***Table 4-3***, quantities are needed to compute total construction costs. To the extent possible, the cost estimation procedure relates the sum of typical line-item quantities to the user inputs for each LID control. As previously stated, the cost estimation procedure is used to develop representative planning-level cost curves for the three design scenarios (simple, typical, and complex). Therefore, simple, typical, and complex quantities are required for each design variable. The next section discusses the definition and derivation of these quantities.

4.3. Defining Simple, Typical, and Complex Design Criteria

To aid in cost estimation for the simple, typical, and complex design scenarios, the project team has evaluated each LID control and defined default design values for each of the influential design variables for each design scenario. In some cases, best professional engineering judgment was needed to assign simple, typical, and complex values, and in such cases, the project team relied on experience designing and implementing LID controls and developing engineering cost estimates, as well as experience in the development of LID manuals, to make the necessary determinations. The results of this exercise are shown in ***Table 4-4*** (for simple design), ***Table 4-5*** (for typical design), and ***Table 4-6*** (for complex design). In these three tables, design variables that are important for performance but have less effect on cost estimates are also indicated. The following list provides a brief rationale for why those variables were excluded.

- **Cistern Emptying Rate** – The costs of rainwater harvesting systems is generally controlled by the number and size of the cisterns. The way in which a cistern is operated does not affect cost, although operation can affect the performance of the cistern.
- **Ponding Height** – Ponding height applies to rain gardens and street planters. This quantity would typically affect costs since greater ponding depth would typically require smaller footprints to capture the same runoff volume. However, if the footprint of a rain garden or street planter is determined based on the percent capture ratio, the ponding height in most cases becomes less consequential in cost estimates and has, therefore, been omitted for the purposes of determining planning-level costs.
- **Soil Media Conductivity** – Soil media conductivity applies to rain gardens, green roofs, and street planters. Similar to the explanation for ponding height, the costs of rain gardens, green roofs, and street planters are influenced more by the footprint areas and media thicknesses and less by soil conductivity, although this variable does impact capture efficiency and treatment performance. Therefore, when the footprint and media thickness are known, soil conductivity becomes inconsequential with respect to costs.

4.3.1. Simple Design Criteria

The values for variables for the simple design scenario are shown in ***Table 4-4***. Characteristics of simple project scenarios include the following:

- New development area, or existing development with unconstrained space for LID control placement down gradient of where the runoff is generated,
- Safe areas for outflow and overflow discharge that are unconstrained,
- Placement location with easy access for equipment and material delivery,
- Flat to moderately flat slopes for LID control placement (e.g., 0–4%),
- Soil infiltration rates at depth of LID control interface with existing subgrade representative of hydrologic soil group (HSG) A soils.

Other characteristics that may place a project into this category include large-scale construction that is believed would benefit from economies of scale and LID control components that are near or below the values presented in ***Table 4-4*** (with the exception of basin depth for infiltration basin, in which greater depths tend to make costs per volume treated lower).

Table 4-4. NSC LID Control Design Values for Simple Design

Variables	Impervious Area Disconnect	Rainwater Harvesting	Rain Garden	Green Roof	Street Planter	Infiltration Basin	Permeable Pavement
Footprint Ratio (% Capture Ratio)	100		2		6	5	100
Cistern Size (gal)		45					
Emptying Rate (gal/day)	*Does not significantly affect costs once cistern size is known*						
Number per 1,000 ft^2		1					
Ponding Height (in)	*Does not significantly affect cost once footprint is known*						
Soil Media Thickness (in)			6	3	12		
Soil Media Conductivity (in/hr)	*Does not significantly affect cost once media thickness is known*						
Gravel Bed Thickness (in)					6		12
Basin Depth (in)						12	
Pavement Thickness (in)							4

4.3.2. Typical Design Criteria

Table 4-5 shows design variable values for the typical design scenario. Characteristics of a typical scenario project include the following:

- New development or existing development with slightly constrained space for LID control placement down gradient of where the runoff is generated,
- Areas for outflow and overflow discharge that are slightly constrained and may require some grading or pipe infrastructure for safe discharge,
- Placement location with fairly easy access for equipment and material delivery,
- Moderately flat slopes for LID control placement (e.g., 4–7%),
- Soil infiltration rates at depth of LID control interface with existing subgrade representative of HSG B soils.

Other characteristics that may place a project into this category include large-scale construction that is believed would benefit from some economies of scale and expected LID control design variables that are near the values presented in ***Table 4-5***.

Table 4-5. NSC LID Control Design Values for Typical Design

Variables	Impervious Area Disconnect	Rainwater Harvesting	Rain Garden	Green Roof	Street Planter	Infiltration Basin	Permeable Pavement
Footprint Ratio (% Capture Ratio)	100		2		6	5	100
Cistern Size (gal)		100					
Emptying Rate (gal/day)	*Does not significantly affect costs once cistern size is known*						
Number per 1,000 ft^2		4					
Ponding Height (in)	*Does not significantly affect cost once footprint is known*						
Soil Media Thickness (in)			12	6	18		
Soil Media Conductivity (in/hr)	*Does not significantly affect cost once footprint is known*						
Gravel Bed Thickness (in)					12		18
Basin Depth (in)						6	
Pavement Thickness (in)							6

4.3.3. Complex Design Criteria

Table 4-6 shows values for design variables representing the complex design scenario. Characteristics of the complex design scenario project include the following:

- Project is on existing development or is a substantial retrofit of existing infrastructure that is likely to have moderate to very constrained space for LID control placement,
- Areas for outflow and overflow discharge that are likely constrained and may require significant grading or pipe infrastructure for safe discharge,
- Placement location with difficult access for equipment and material delivery,
- Steeper slopes for LID control placement (e.g., greater than 7%),
- Soil infiltration rates at depth of LID control interface with existing subgrade representative of HSG C and D soils.

Other characteristics that may place a project into this category include implementation of LID controls in difficult locations or with other complex designs. This could be due to high anticipated loadings or requirements to treat complex pollutants of concern. Projects that have LID control design variables that are equal to or greater than the values presented in ***Table 4-5*** would also fall into the complex design criteria.

Table 4-6. NSC LID Control Design Values for Complex Design

Variables	Impervious Area Disconnect	Rainwater Harvesting	Rain Garden	Green Roof	Street Planter	Infiltration Basin	Permeable Pavement
Footprint Ratio (% Capture Ratio)	100		2		6	5	100
Cistern Size (gal)		5500					
Emptying Rate (gal/day)	*Does not significantly affect costs once cistern size is known*						
Number per 1,000 ft^2		100					
Ponding Height (in)	*Does not significantly affect cost once footprint is known*						
Soil Media Thickness (in)			36	12	24		
Soil Media Conductivity (in/hr)	*Does not significantly affect cost once footprint is known*						
Gravel Bed Thickness (in)					36		36
Basin Depth (in)						24	
Pavement Thickness (in)							9

Finally, the information on design and site characteristics are included in a design category table for decision making. ***Table 4-7*** demonstrates the evaluation of each design category and the scoring assigned based on an example user input. If the summed strike tallies are tied between design categories, then the more complex category is assigned.

Table 4-7. Selection of Control Design Values Based on Critical Cost Characteristics

Variables	Example User Input Values	Category Tally Assignments			Category Tally Score		
		Simple	Typical	Complex	Simple	Typical	Complex
New Development?	1	1	0	0	1	0	0
Redevelopment?	0	0	1	1	0	0	0
Is there pretreatment?	0	0	0	1	0	0	0
Site Suitability is Relatively Poor	1	0	0	1	0	0	1
Site Suitability is Moderate	0	0	1	0	0	0	0
Site Suitability is Excellent	0	1	0	0	0	0	0
Topography is Flat (2%)	0	1	0	0	0	0	0
Topography is Moderately Flat (5%)	0	1	1	0	0	0	0
Topography is Moderately Steep (10%)	1	0	1	1	0	1	1
Topography is Steep (15%)	0	0	0	1	0	0	0
Hydrologic Soil Type A	0	1	0	0	0	0	0
Hydrologic Soil Type B	0	0	1	0	0	0	0
Hydrologic Soil Type C	0	0	0	1	0	0	0
Hydrologic Soil Type D	1	0	0	1	0	0	1
TOTAL COUNT					**1**	**1**	**3**

Based on the above tally assignment scores, the category assignments resulted in the user input for the site to be categorized, based on the category tally totals, into a complex scenario.

4.4. Development and Application of Cost Curves

4.4.1. Cost Curve Production

1. The goal of adding costs to the NSC was to apply design information provided (or assumed) by calculator users, along with user input on other critical variables that affect costs, to develop curves that can be applied to easily calculate project costs. Using the simple, typical, and complex design variables defined in the previous section, the Project Team developed a cost estimation framework for producing families of curves for each of the three design scenarios and for each of the seven supported LID controls (total of 21 curves; vegetated swales have been excluded as these are often sized by flow rather than volume or can simply be calculated based on a linear relationship of length [in feet] of swale). The cost curve production framework consists of a Microsoft Excel spreadsheet that computes capital costs for various sizes of LID controls that are based on itemized costs and quantities computed from the user-defined design variables. Microsoft Excel macros were used to automate the process of repeatedly sizing and costing the various LID controls for the various scenarios. The process includes iteratively cycling through each of the seven LID controls (as applicable) through the following steps: Select a size of LID control that is within the functional range (4.4 ft^2 to 21.78 million ft^2),
2. Compute cost quantities for that size for the simple, typical, and complex design scenarios,
3. Sum the itemized unit costs, apply contingencies, and compute total capital cost,
4. Record total capital cost in the appropriate location to allow cost-curve plotting based on LID control type, size, and design category (i.e., simple, typical, complex).

The result of executing the above procedure produces 21 cost curves that are plotted for each LID control selected on one chart, as well as on separate charts, by LID control type. ***Figure 4-1*** demonstrates the developed cost curves for rain gardens. See Appendix A for all 21 curves. The cost curves are plotted with LID control footprint surface areas in square feet (cistern as storage capacity in gallons) on the x-axis and total capital cost on the y-axis.

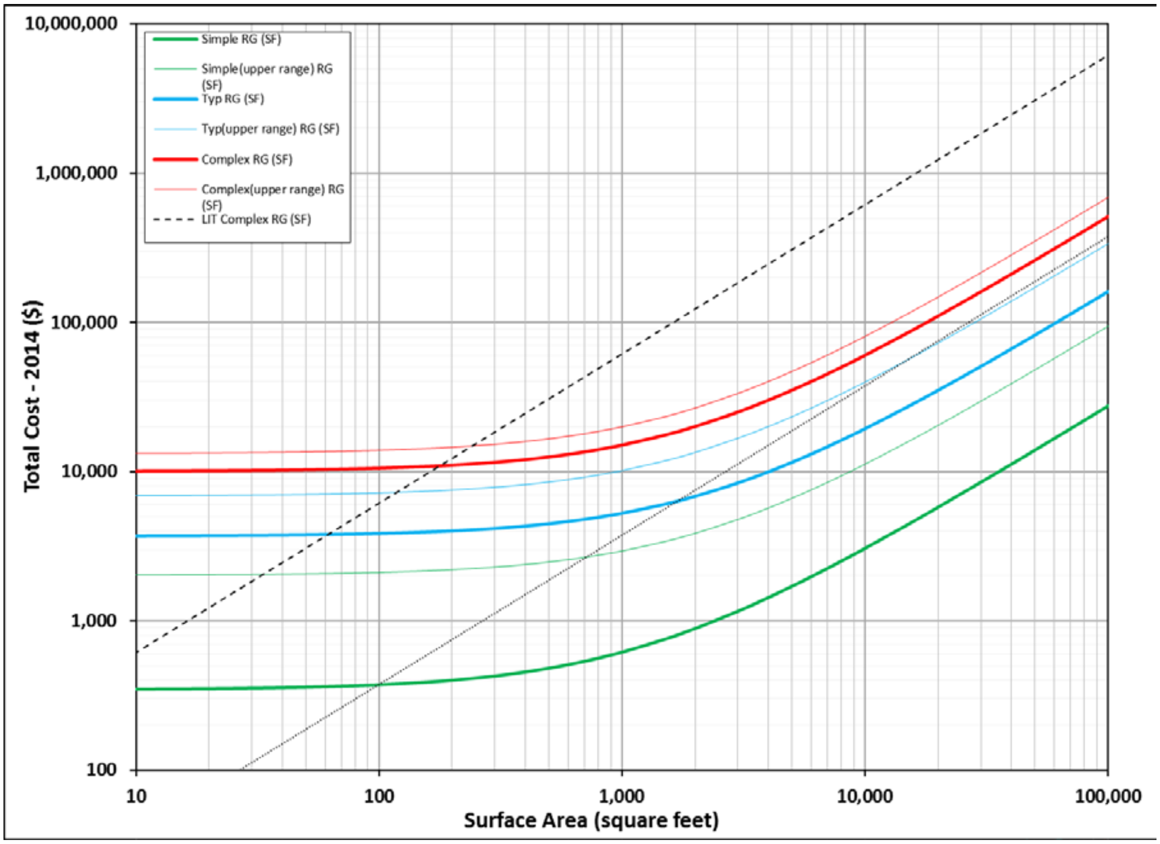


Figure 4-1. Rain Garden Cost Curve

Once the cost curve generation framework was vetted, implemented, and validated, unit costs, sizing parameters, and other critical cost factors were dynamically linked to the cost curves. These variables can be changed and updated with cost curves generated by clicking on the appropriate button. Applying this approach is expected to facilitate future maintenance and updating of the cost data and estimation procedure if changes are necessary.

4.4.2. Cost Curve Application

The role of the cost curves in the cost estimation procedure is to allow costs to be quickly interpolated based on user inputs. The curves are produced with LID control size on the x-axis and capital cost on the y-axis. Once the appropriate curve has been determined for the LID control in question, the next step is to locate the appropriate LID control size on the x-axis and read the corresponding cost based on the curve. The cost curves have been designed to provide a range of costs that bracket potential project costs using the three design scenarios (simple, typical, or complex). Once an applicable design scenario has been determined, a cost range is obtained, as shown in ***Figure 4-2***. This cost range is a necessary approach because it communicates to the user that there is uncertainty associated with the estimates. A simple design reports a range with the low curve value as the low end of the range and the typical curve value as the upper end of the range. A typical design similarly reports the range as the value determined from the typical curve and complex curve values. The complex curve computes the difference between the complex and the typical and adds it to the complex value to produce the range representing the complex design scenario. The range for this scenario, therefore, has the complex curve value as the lower bound of the range and the difference between complex and typical curve values as the upper bound of the range.

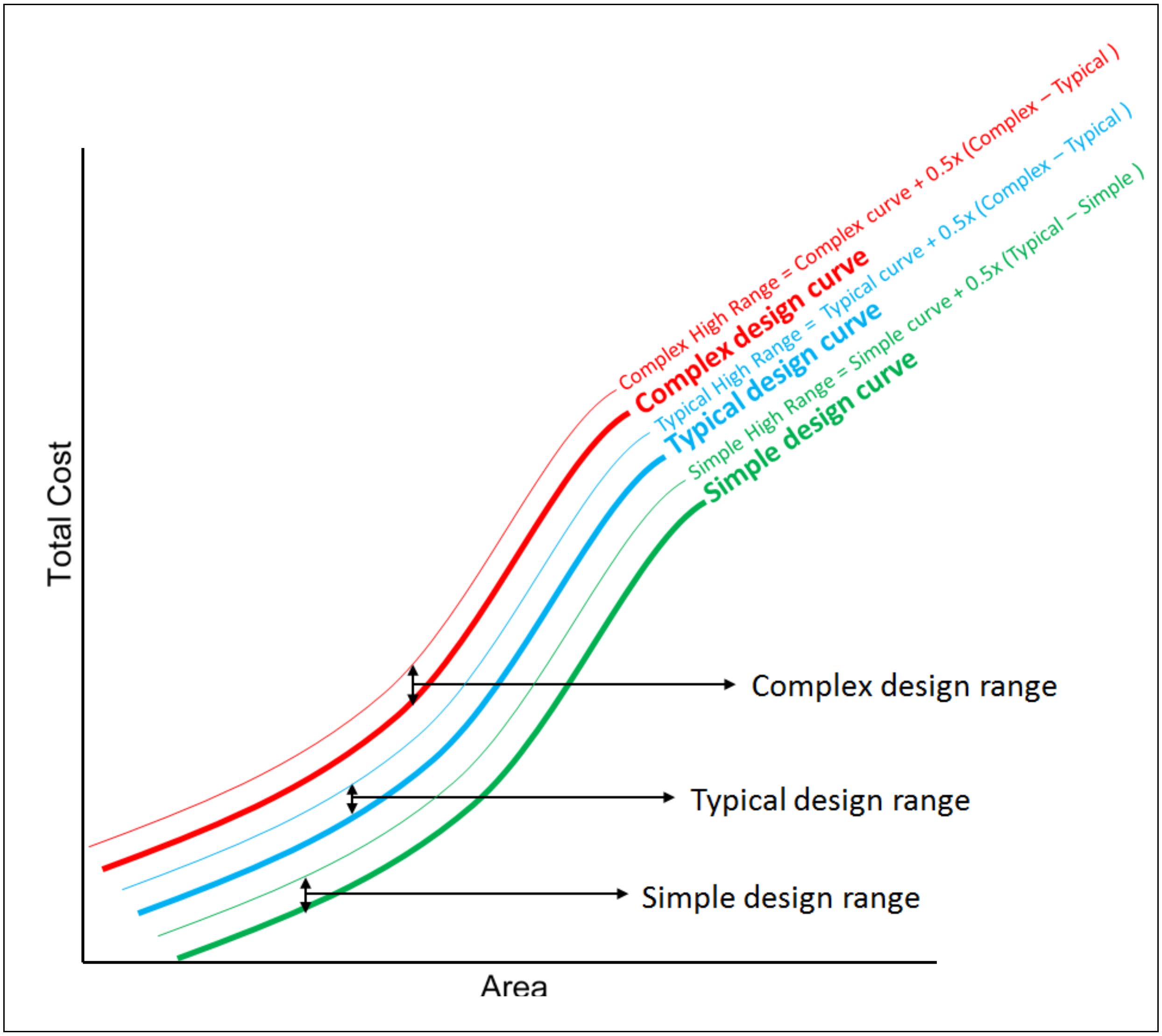


Figure 4-2. Obtaining Cost Ranges from Cost Curve Range

To facilitate the incorporation of the cost estimation procedure into the NSC, trend lines have been created for each curve and regression equations have been computed based on the trend lines. The regression equations are easy to program and will be used in the NSC to simulate reading from the cost curves.

4.4.3. Comparison of Cost Curves to Literature Values

Once the cost curves were developed, the high (complex) and low (simple) values of construction costs from literature were also plotted to compare the curves to literature values. ***Table 4-8*** includes the literature values that were used in Task 2 and were plotted alongside the cost curves. All values were converted to 2014 dollars. The cost curves and plotted literature values can be found in Appendix A. Although literature values tend to overlap with the cost curves that were developed, a lack of specific information from the literature concerning site conditions and construction costs somewhat limits the comparability of literature values to the cost curves.

Table 4-8. Literature Review Construction Costs for Comparison with Cost Curves

LID Control	Simple	Complex	Sources
Impervious Area Disconnection	$2.40/ft^2	$6.50/ft^2	NC-DSWC, 2006 (Note* This study used pavement removal for impervious disconnection)
Rain Harvesting	$0.50/gal of storage	$8/gal of storage	Hunt and Szpir, 2006; TWDB, 2005, U.S. EPA, 2013; NC-DSWC, 2006
Rain Gardens	$3/ft^2	$40/ft^2	Brown and Schueler, 1997; NC-DSWC, 2006; Iowa Stormwater Partnership, 2008; Lake Superior Streams, 2014; LID Center, 2014
Green Roofs	$9.60/ft^2	$40/ft^2	NC-DSWC, 2006; GSA, 2011; Peck and Kuhn, 2001; Virginia DEQ, 2011b
Street Planters	$30/ft^2	$50/ft^2	BES, 2005a; WERF, 2009
Infiltration Basins	$1.30/ft^2	$11/ft^2	U.S. EPA, 1999a; MPCA, 2011;
Permeable Pavement	$2/ft^2	$16/ft^2	SCSMC, 2008; WERF, 2009

4.4.4. Maintenance Costs

The maintenance costs discussed in **Section 2**, Literature Review, have also been included for users to better understand these costs when planning LID controls (***Table 4-9***). The maintenance costs are dependent upon the type of LID control and whether it is a private residential installation or a professionally managed system of LID controls. All values were converted to 2014 dollars and represent the cost of maintenance annually. A range of maintenance costs is presented to users of the NSC, along with the capital costs.

Table 4-9. Annual Maintenance Costs for Comparison with Cost Curves

LID Control	Simple	Complex	Sources
Impervious Area Disconnection	$0.04/ft^2	$0.06/ft^2	Engineers Opinion of Probable Cost
Rain Harvesting	$0.075/gal	$0.24/gal	LID Center, 2005; SBPAT Tool, 2005
Rain Gardens	$0.06/ft^2	$1.45/ft^2	CNT, 2009; MPCA, 2011
Green Roofs	$0.03/ft^2	$0.20/ft^2	BES, 2008; Peck and Kuhn, 2001
Street Planters	$0.04/ft^2	$0.80/ft^2	BES, 2005a; WERF, 2009
Infiltration Basins	$0.04/ft^2	$1.32/ft^2	Weiss et al., 2005
Permeable Pavement	$0.05/ft^2	$0.23/ft^2	CNT, 2009; LID Center, 2005; MPCA, 2011

Cost curves for maintenance are included in Appendix B.

4.5. Programming Considerations

One of the primary benefits of the cost curve approach to cost estimation is the relative ease of programming when properly implemented. The approach selected for curve development simplifies cost estimation conceptually by incorporating the complexities related to the analysis using unit costs and other critical design variables into curves based simply on LID footprint. The curves themselves can be reduced to regression equations by plotting trend lines and obtaining equations for the trend lines. Once regression equations have been developed, it is relatively straightforward to program the equations.

Table 4-10 shows the regression equations that were developed for the cost estimation procedure using the cost curve production framework.

Table 4-10. LID Control Cost Curve Regression Equations

LID Control	Simple Cost Curve	Typical Cost Curve	Complex Cost Curve
Impervious Area Disconnect	y = 0.2142x + 159.75	y = 3.65x + 1922.8	y = 5.7238x + 3806.5
Rainwater Harvesting	y = 0.3844x + 61.8	y = 0.7697x + 3564	y = 1.4085x + 4350
Rain Garden	y = 0.2717x + 346.08	y = 1.5691x + 3696	y = 4.6378x + 10052
Green Roof	y = 0.5421x + 1975.2	y = 2.5009x + 3288	y = 7.5401x + 20824
Street Planter	y = 0.5592x + 1928.2	y = 2.7125x + 2580.6	y = 10.357x + 14163
Infiltration Basin	y = 0.8205x + 1928.2	y = 0.8473x + 3864	y = 3.7531x + 13050
Permeable Pavement	y = 2.3502x + 1545	y = 4.7209x + 1800	y = 7.8694x + 3750

4.6. Limitations

The limitations of the cost estimation procedure fall into three categories, as follows:

- Limitations due to unsupported cost variables,
- Limitations due to internal interpolations,
- Limitations due to changing unit costs.

Table 4-11 shows several cost variables that were identified in the literature review phase but that are not supported in this effort, and yet may have a measurable affect for some projects. Most of the factors in the table fall outside the scope of what many planning-level cost estimation tools such as NSC typically consider. The cost of some of these variables, if known, can be added onto (or subtracted from) the cost output of the tool. Similarly, it might be possible to “represent” some of these costs through changing the type of project (simple, typical, or complex) in the direction in which the excluded variable is known to have shifted the actual cost.

The cost-curve approach is inherently dependent on interpolations that can introduce some error in the estimates produced. This is largely mitigated by providing the results as a range that is intended to capture variability and error rather than reporting a single value. This is the purpose of including the range of costs.

Finally, swings in the economy often affect material and labor costs. In addition, there may be significant differences in costs based on local or regional supply and demand for materials and labor. As such, actual unit costs may be different than the unit cost data collected in this effort. This is a limitation that is shared by most cost estimation tools and may be mitigated by frequent updates to the underlying unit cost data. However, providing a range of estimated cost data reduces the frequency necessary to update costs and may capture minor changes in the economy. With the intent to use the tool as a planning-level estimation only and through the approach of reporting costs as a range, many of these limitations may be reduced or even eliminated by capturing this variation in the range presented. Even with this approach, however, there will be a need to update costs at some point in time.

Table 4-11. Summary of Cost Variables Excluded from NSC Cost Estimation Procedure

Cost Variable	Potential Effect and Mitigation
Presence or absence of reinforcement for stability	Most LID controls do not require reinforcement, so the impact of this exclusion is expected to be minimal. If design of the LID control will require measures for instability, these costs can be added to the range provided by the calculator.
Need for land acquisition	Land costs are variable based on location and region. These costs, if necessary in LID control design, can be added to the estimate obtained from the calculator.
Project purpose (e.g., demonstration project)	Costs are often increased by first-time pilot or demonstration projects, as the uncertainty requires LID control sizes to meet greater margins of safety or account for unknown circumstances. Users may shift the design scenario to the next category above that assigned, or include a separate contingency to account for this variable. Adjustments should be made on a case-by-case basis.
Regulatory and permitting requirements	Regulatory and permitting requirements vary by location. It is recommended that these costs be estimated separately and added to the total reported costs.
Design requirements	The range of costs provided account for standard, typical LID control designs. If designs depart significantly from this, users can include added costs to account for atypical designs if this is known.
Public vs. Private projects	The effect of public versus private installation costs is not well-documented. If known, an additional contingency factor can be applied to improve estimates.
Partnerships with others	The effect of partnerships is difficult to predict. To include, the user will need to understand whether the partnership may reduce costs (e.g., volunteer labor, donated material) or may increase costs (e.g., increased planning with a greater number of interested parties). This information may shift a project between scenarios or may require additional cost procedures to account for partnerships.
Level of experience of designers and contractors	Costs often increase when inexperienced contractors do projects as the uncertainty requires LID control sizes to meet greater margins of safety or account for unknown circumstances. Users may shift the design scenario to the next category above that assigned or include a separate contingency to account for this variable.

5. COST ESTIMATION PROCEDURE VERIFICATION

A QAPP was developed to ensure that the outcome of this project is of reasonable quality and that the work products are fit for their intended use, in accordance with EPA quality system requirements defined in EPA Order CIO 20105.0 (U.S. EPA Order; formerly EPA Order 5360.1 A2), *Policy and Program Requirements for the Mandatory Agency-wide Quality*, including the requirements of the *Guidance for Quality Assurance Project Plans for Modeling.* The QAPP states that trends and relationships developed will be verified and that the method of verification may include application of the procedures to a case study to validate. The calculations and results from the case study are formatted and presented in a way that makes them useful as examples for programmers and for verification of requirements, development of unit tests during construction, and as a basis for final acceptance tests prior to release of the NSC.

5.1. Case Study: Commercial Site in Greenland, NH

To validate the approach of the cost tool, as well as the cost data and estimation procedures, a case study was developed based on actual project implementation. The case study is part of the Greenland Meadows retail center built in 2008 in Greenland, NH (see ***Figure 5-1***). The site encompasses a total of 56-acres and is 45.7% impervious. Two porous asphalt areas, as well as a sub-surface gravel wetland (for water quality treatment), were installed for stormwater management on the site in lieu of traditional stormwater management consisting of traditional pavement with a subsurface detention system.

Figure 5-1. Case Study – Greenland Meadows Site Location, Greenland, NH

5.1.1. Site Description

In order to verify the NSC cost estimation procedure, the portion of the site that drains to a porous asphalt parking lot was examined. The sub-surface gravel wetland cost and drainage area was excluded because the NSC does not currently support this LID control. The drainage area to the main porous asphalt parking lot is 15.42 acres and is approximately 93.6% impervious. The surface area of the porous asphalt

LID control is 3.29 acres (143,296 ft^2). From the soil survey data information in the NSC, it was determined that the site has Type C HSG, a moderately flat slope (5%), and a soil drainage rate of >0.1 to <=1.0 inches/hour. A value of 0.5 inches/hour was used for evaluation of LID control performance. Screenshots of the NSC tool are presented in

Figure 5-2, and a summary of site characteristics are presented in ***Table 5-1***.

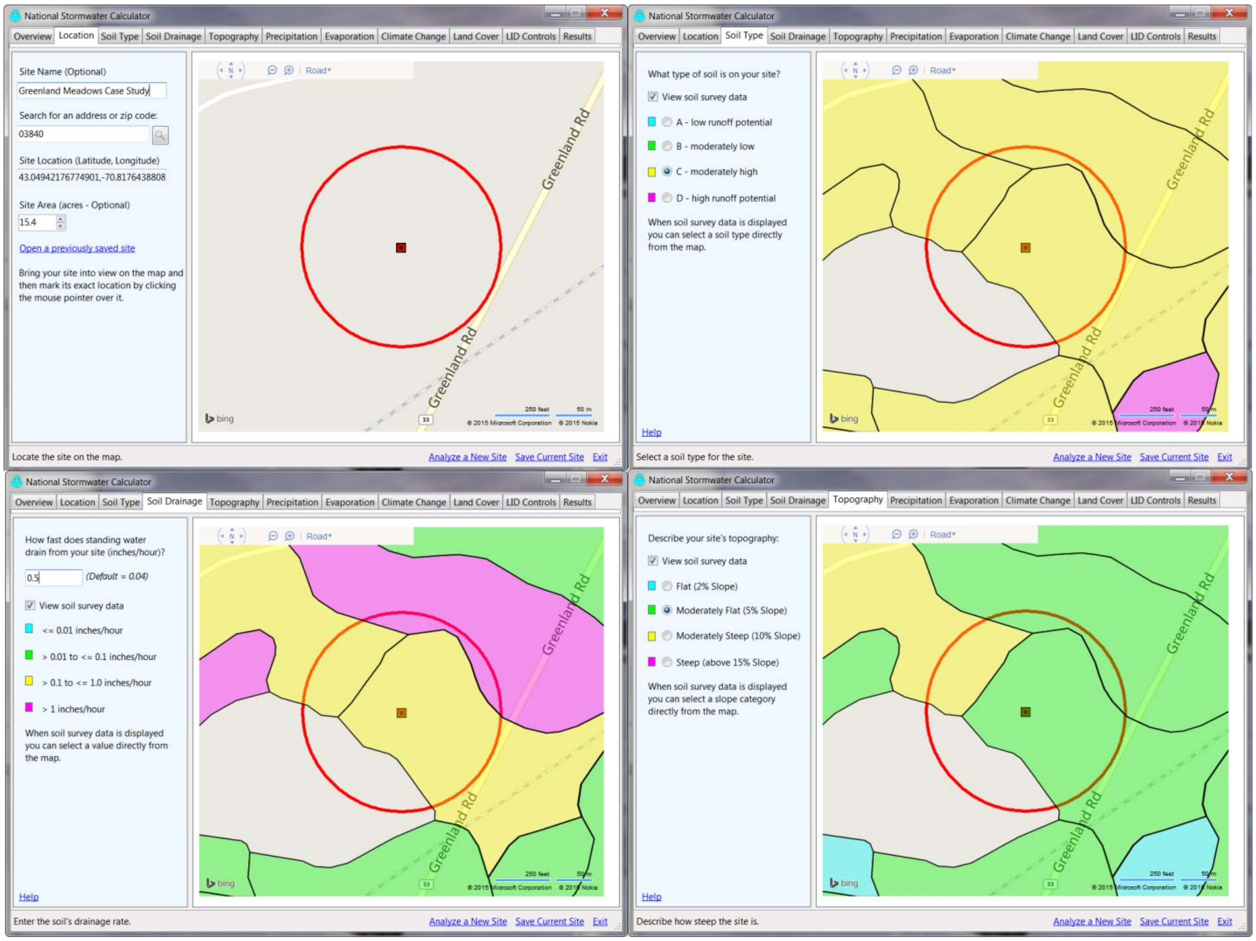


Figure 5-2. Greenland Meadows Case Study NSC Input Variables

Table 5-1. Greenland Meadows Case Study Site Characteristics

Variable	Value
Total Area (acre)	15.42
Estimated Imperviousness (%)	93.6
Site soils	Type C
Soil Drainage (in/hr)	0.5
Topography	moderately flat
Permeable Pavement Surface Area	3.29 acre (143,296 ft^2)

5.1.2. Cost Estimation

The cost data and estimation procedure uses the information collected in other NSC input fields to determine the design scenario (simple, typical, or complex) should be applied to the project site. For example, from the Soil Type and Topography tabs that already exist in the calculator, the following information is recorded and used for the Greenland Meadows Case Study:

- Site Soils = HSG C,
- Topography = Moderately Flat (5%).

The other information that is required to complete the assessment for the design scenario category and would appear on the LID Control Cost Tab is shown in ***Table 5-2***. The responses to these for Greenland Meadows are also shown in the table.

Table 5-2. Case Study – Site and Construction Feasibility Constraints

Design Scenario Variables	Cost Tab Information		Cost Tab Interpretation
Is the site a New Development or a Redevelopment Project?	New Development Redevelopment	◉ ○	New Development
Does the LID control include Pretreatment?	Yes No	○ ◉	No
What is the site suitability for including LID controls? (see explanations in **Section 3.2**)	Relatively Poor Moderate Excellent	○ ◉ ○	Moderate

With the responses to these questions and the information generated from the other tabs, the corresponding design scenario curve can be applied to the cost estimation procedure (as shown in ***Table 5-2***) to determine which design scenario should be applied.

The Greenland Meadows site has the following characteristics: the site is new development (simple design scenario), has moderate site suitability (typical design scenario), is moderately flat (simple design scenario), and has type C HSG (complex design scenario). This information alone would put the site into the simple design scenario. However, because the project is already completed, the design variables must be examined more closely to verify the design scenario.

Table 5-3 includes the design variables that are typical for the simple, typical, and complex design scenarios, along with the known design variables for the case study.

Table 5-3. Case Study – Comparison of Greenland Meadows Permeable Asphalt Design Variables with Categories Assigned to the NSC

Permeable Surface Variable	Simple Design	Typical Design	Complex Design	Greenland Meadows Design
Pavement Thickness (in)	4	6	9	3
Gravel Layer Thickness (in)	12	18	36	55

From ***Table 5-3***, one can observe that although the site and feasibility constraints indicate that the project would be categorized as a "simple" design scenario, the gravel thickness suggests that a typical or even complex design scenario may be more representative of the design. From detailed cost information from the case study, the site has custom design elements that are not characteristic of simple designs. For example, the permeable pavement includes a 12-inch sand filter layer, which is not typical of most permeable pavement designs and is not an option supported by the NSC at this time. Additionally, the gravel reservoir layer is about 54 inches in depth, which is much greater than the 12 inches that has been defined for simple design scenarios. It should also be noted that the maximum depth of the gravel layer in the NSC is 36 inches. ***Figure 5-3*** shows how this design would be best represented using the current version of the NSC. Therefore, the large gravel reservoir layer and the additional 12-inch sand layer specified in the Greenland Meadows case study is not well represented by the simple design category. Users of the NSC should be aware of the default design variables for the LID controls of interest as applied in the NSC to better categorize anticipated planning level designs into the most appropriate design category.

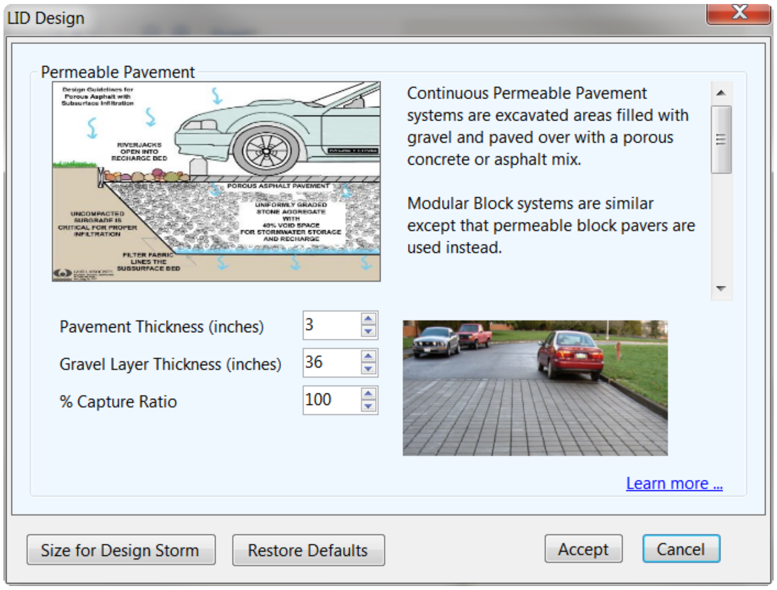


Figure 5-3. Case Study – Permeable Pavement Design Variables

As described in **Section 4.4**, the cost curves use the LID control footprint (or storage capacity in the case of cisterns) as a determinant on the x-axis and cross reference to the y-axis to determine the estimated capital cost. For each of the LID controls, the calculated footprint or storage capacity is used to determine the range of capital costs for appropriate cost curves. Based on the discussion of the site and feasibility constraints and the design variables, the Greenland Meadows case study capital costs are compared to both the typical design scenario costs and the complex design scenario costs. The results of this exercise are shown in ***Table 5-4***. Note that the actual cost of the Greenland Meadows Case Study excludes the material for the 12-inch sand layer, as this cost item is not supported as a part of NSC permeable pavement design.

Table 5-4. Case Study – LID Control Capital Costs

Design Scenario	NSC Estimated Cost	Actual Greenland Meadow Case Study Cost
Typical	$678,300–$904,850	$1,061,400
Complex	$1,131,400–$1,357,950	

The results of this exercise demonstrate that although the NSC and NSC cost estimation procedure have limitations that may not accommodate all design scenarios, the development of planning-level cost scenarios do provide an adequate understanding of general costs for this case study. This particular case study was believed to be a typical or complex design scenario based on the large gravel storage layer. The approached developed has the flexibility to allow the user to adjust the design scenario to accommodate planning information that may not be captured in other parts of the NSC.

6. CONCLUSIONS

This document details the development of a cost estimation procedure for LID controls for inclusion in the NSC based on reported unit capital costs. The integration of cost estimation into the NSC is anticipated to add to the current functions of the NSC and promote the use of the calculator. The approach that has been developed matches the ease of use and complexity of the current version of the NSC. The cost estimation procedure developed is based on the use of unit cost information to create curves for varying complexities of LID control implementation. The resulting cost estimates report a range in costs to demonstrate the potential variability that can be tailored to each design scenario and to communicate uncertainties in the cost estimates.

To verify the cost data and estimation procedure, a case study assessing cost information for a site in Greenland, NH, was used to compare with cost data estimated using the NSC. The results obtained from applying the procedure were compared to values from other approaches and found to reasonably bracket much of the cost information but still provide useful information to the user.

The approach used considered some of the intricacies of programming during implementation. To improve the anticipated programming and maintenance process, the curves can be easily represented as regression equations based on variables that are available in the current version of the NSC. The programming is, therefore, expected to be straightforward and easy to apply.

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