

Final Methodology and Results Report

National Stormwater Calculator: Low Impact Development Stormwater Control Cost Estimation Programming

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EXECUTIVE SUMMARY

The purpose of this Task Order (TO) 026 was to add cost estimation procedures for Low Impact Development (LID) stormwater management controls (SMCs) to the EPA National Stormwater Calculator (SWC). Adding cost estimation capabilities to the SWC is anticipated to further enhance the popularity of the SWC and promote the use of the calculator by new users. While the current tool estimates runoff at a site based on soil type, topography, existing climate, and potential future climate conditions, the addition of cost estimates will allow planners and managers to compare performance of SMCs based on cost estimates.

The SWC has been updated to use the size and configuration of SMCs along with other important variables such as whether the project is being applied as part of a new development or redevelopment project to estimate costs. Similarly, potential site constraints such as permeability, slope, and other factors that could potentially result in different sizes and configurations are included to account for the costs that these constraints might add. The updated SWC matches the ease of use of the current version. The cost estimation approach employed is based on the application of unit cost information to create curves for varying complexities of LID control implementation (previously developed under TO 019 (PR-ORD-14-00308)). An approach for regionalization of costs across the nation was developed using data from BLS. The regionalization approach allows the calculator to account for regional differences in LID control implementation costs around the country. The calculator dynamically obtains Bureau of Labor Statistics (BLS) data via the BLS application programming interface (API) version 2 (<http://api.bls.gov/publicAPI/v2/>) and then computes and applies the regionalization multiplier for the user.

The results produced by the updated SWC are both tabular and graphical outputs representing estimates of probable capital and annual maintenance costs. Highlights of the features of the expanded SWC include:

- Dynamically obtains BLS data based on the location of the study area to compute a regionalization multiplier
- Dynamically applies an inflation adjustment factor computed using BLS data and the current year at the time of execution
- Produces cost estimates that account for development type (i.e., new development versus redevelopment)
- Accounts for construction feasibility via site suitability options (including poor, moderate, or excellent site suitability)
- Produces tabular results that show estimates for two scenarios side-by-side, as well as the difference between the scenarios
- Produces a graphical summary of the results using dynamic vector graphs with interactive tool tips.

To verify the cost estimation methodology and the updated SWC, a case study including cost information for a site in Dillwyn, Virginia, with known LID implementation costs was used to compare to estimates obtained from the SWC. The results obtained were found to reasonably bracket the estimate from the site.

SECTION 1. Introduction

1.1 Project Description and Objectives

The U.S. Environmental Protection Agency's (EPA) Performance Work Statement (PWS) for Task Order (TO) 026 (PR-ORD-15-00668), National Stormwater Calculator: Low Impact Development Stormwater Control Cost Estimation Programming, states that the purpose of this TO is to implement cost estimation procedures for Low Impact Development (LID) controls previously developed as part of TO 0019 (PR-ORD-14-00308). This project involves programming of the previously developed cost curves and methodology into the existing National Stormwater Calculator (SWC) desktop application. The integration of cost components of LID controls into the SWC will increase its functionality and is expected to promote greater use of the SWC as a stormwater management and evaluation tool. The current SWC estimates runoff at a site based on soil type, landscape and land use information, existing and potential future climate conditions, and stormwater management controls (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. Cost estimation is accomplished based on user-identified size (or auto-sizing based on achieving volume control or treatment of a defined design storm) and configuration of the LID control infrastructure along with other key project and site-specific variables, including whether the project is being applied as part of a new development or redevelopment project. The implementation of cost estimation support in the SWC accounts for potential site constraints such as permeability, slope, and other factors that may result in different LID control sizes and configurations and associated additional expenses.

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 and implemented in the updated SWC are not recommended for engineering estimates but are for relative comparison of stormwater controls.

SECTION 2. Methodology and Approach

The cost estimation approach implemented in the SWC is based on the use of previously developed cost curves for each of the LID controls supported. The process of creating the cost curves is described in detail in the TO 019 (PR-ORD-14-00308) Final Report. This Task Order included a literature review to develop a cost estimation procedure based on the 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 with LID control implementation to communicate uncertainties in cost estimates. The cost curve production framework used Microsoft™ Excel spread sheet to compute capital and maintenance costs for various sizes of LID controls based on generally assumed LID control construction item costs and quantities. Microsoft™ Excel macros were used to automate the process of repeatedly sizing and costing the various LID controls for the various scenarios. (See Appendix A of the TO 019 [PR-ORD-14-00308] Final Report for all 18 curves.) This document details improvements on TO 019 by including tailored estimates that incorporate the opportunity to apply regional differences in cost across the country to adjust cost estimates by region and to correct for inflation based on the current year. A more detailed discussion of how the cost curves were applied and the cost regionalization adjustment approach is discussed next.

2.1 Application of Cost Curves

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 2-1 shows the regression equations that were developed for the cost estimation procedure using the cost curve production framework.

Table 2-1. 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	$y = 2.3502x + 1545$	$y = 4.7209x + 1800$	$y = 7.8694x + 3750$

2.2 Cost Regionalization Approach

Many cost estimation techniques employ nationwide, disaggregated data to provide more robust, tailored regional estimates. Several data sources such as Engineering News Record (ENR) and RS Means (The Gordian Group) provide the ability to develop regionalized costs (e.g., for select cities). However, these sources of information require subscriptions that can be quite costly over the long term and will continue to require annual maintenance by EPA to incorporate into the SWC. The approach outlined in this section provides a more effective, long term solution that requires less maintenance by EPA.

The approach provides reasonable approximations to express national cost values in regional terms using readily available BLS data. The BLS data set can be obtained online at monthly and annual intervals, with calculated indices providing annual cost adjustments as well. Due to online accessibility, the SWC can dynamically obtain BLS data in real-time during SWC program executions, as is currently done with soil, precipitation, and evapotranspiration data. The end product of this effort is a regional cost multiplier that is applied to the SWC cost estimate to provide more current, tailored, regionally representative cost.

The cost regionalization approach consists of seven steps described as follows.

Step 1 – National PPI Variables Data Collection

The team downloaded BLS Producer Price Index (PPI) categories/variables and assessed this data set for costs that are most likely to be included in LID controls construction. PPI variables are the outputs of industries such as service, construction, utilities, and other goods-producing entities, and are only available on a national scale. Documentation of data collection and quality assurance and quality control procedures for the data are available from the BLS website at <http://www.bls.gov/bls/quality.htm>. Relevant PPI data include items/categories such as concrete storm sewer pipe, asphalt paving mixture, engineering services, and construction sand and gravel. See Table 2-2 for a list of the selected PPI variables that were determined to be relevant to BMP construction. Data were downloaded for appropriate PPI variables that had sufficient recording periods (>20 years). A period of record of 20 years was used to assure that adequate BLS data was available to statistically represent the fit of the model to estimate the current and historic national variability reported via RS Means indices.

Table 2-2. Potential BLS PPI Variables

Cost Variable	Starting Year	Cost Variable	Starting Year
All other plastic pipe, incl. storm drain	2012	Nursery, garden and farm supply services	2003
Asphalt and tar paving mixture	2005	Plastic water pipe	1988
Asphalt paving mixtures and block manufacturing	1976	Ready mix concrete manufacturing	1965
Burial vaults and boxes, precast concrete	1978	Real estate brokerage, nonresidential	2010
Concrete contractors, nonresidential building	2008	Regular gasoline	1977
Concrete culvert pipe	2000	Tractor shovel loaders (skid steer, etc.)	1976
Concrete pavers	1981	Transportation engineering products	2010
Concrete storm sewer pipe	2000	Wood chips	1981
Construction sand and gravel	1982	Non-building related engineering projects	1997
Diesel fuel	1985	Nursery, garden and farm supply services	2003
Dump trucking	2015	Plastic water pipe	1988
Engineering Services	1997	Ready mix concrete manufacturing	1965
Graders, rollers and compactors	2004	Real estate brokerage, nonresidential	2010
Non-building related engineering projects	1997		

Step 2 – National CPI Variables Data Collection

The TO 026 team downloaded BLS Consumer Price Index (CPI) variables for costs that are most likely to contribute to LID / BMP construction costs from the BLS database. CPI data, while more limited than PPI data, represent regional/city data that can be used to regionalize the national SWC costs. The CPI variables were combined with the PPI variables from Step 1. The CPI variables that were identified for analyses are shown in Table 2-3. Data for each region/city were downloaded for CPI variables with recording periods of >20 years. Looking at historic data allows for predictive relationships to represent the long term relationship, a goal for this product.

Table 2-3. Potential CPI Variables

Cost Variable	Starting Year
Purchasing power of the consumer dollar	1980
Durables	1980
Fuels and utilities	1980
Services	1980
Utilities and public transportation	1980
Transportation	1980
Transportation commodities less motor fuel	2009
Fuel oil and other fuels	1980
Energy services	1980
Water and sewerage maintenance	1980
Motor fuel	1980
Gasoline (all types)	1980

Step 3 –National PPI Data Correlated to RS Means

Step 3 determined PPI variables for use in the model. PPI data were statistically compared with national RS Means Historic Cost Index. Initially, all variables were compared by developing a model which applied the linear least squares fitting method that minimizes the sum of the squares of the residual values. The team examined the r-squared value, p-value, the F-statistic, residuals plot, and line fit plot to evaluate whether the model provided output that was comparable to RS Means Historic Cost Index.

A regression analysis was performed for data sets that contained complete data from 1986 to 2015. The PPI variables that were found to represent the longer term variability in RS Means Historic Cost Index included Ready-mix concrete, tractor shovels, and diesel fuel. Figure 2-1 demonstrates an example of the residual and line fit plots for regular gasoline with RS Means. The residuals plot shows a clustering of data point rather than no apparent clusters, indicating the model may be suspect. Similarly, the line fit plot does not show a clear linear relationship, also suggesting a linear function is not well suited to be comparable to RS Means Historic Index. Therefore, regular gasoline was eliminated from further analysis.

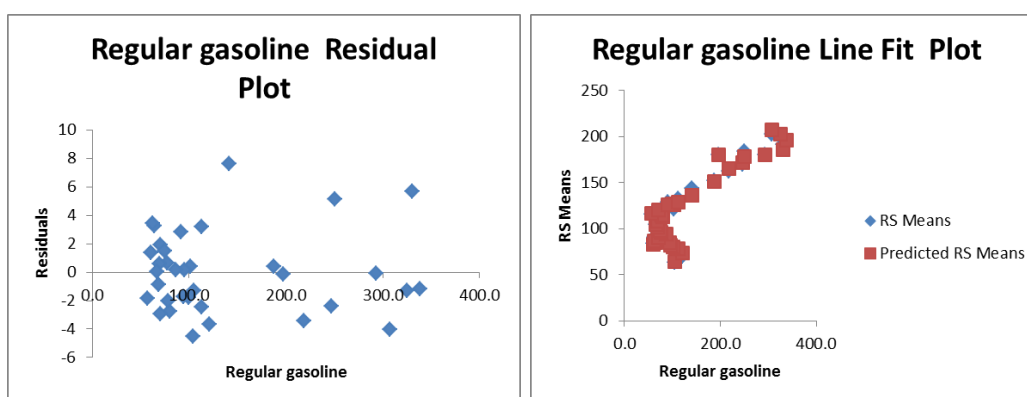


Figure 2-1. Regular gasoline residual and line plot.

Additional regressions were completed to demonstrate the proof of concept. Ultimately, the best combination of variables was found to be Ready-mix concrete, diesel fuel, and tractor shovel loaders. The residual plots, the line fit plots, and the r-squared value, and p-values met the criteria for inclusion in the model. The regression between Ready-mix concrete, diesel fuel, tractor shovel loaders, and RS Means was found to be a representative model. The results are shown below in Table 2-4 and Table 2-5 and Figure 2-2.

Table 2-4. Comparison Statistics for the Cost Estimation Model Using Ready-mix Concrete Manufacturing, Diesel Fuel, and Tractor Shovel Loaders

<i>Comparison Statistics</i>	
Multiple R	0.997121
R Square	0.99425
Adjusted R Square	0.99356
F-statistic	$F_{1,29} = 1440.9, p < .0001$

Table 2-5. Coefficients and p-values for the Regression between RS Means and Ready-mix Concrete Manufacturing, Diesel Fuel, and Tractor Shovel Loaders

	<i>Coefficients</i>	<i>p-value</i>
Intercept	-14.4466	0.00037
Ready-mix concrete manufacturing	0.464754	3.99E-07
Diesel fuel	0.05761	0.00016
Tractor shovel loaders	0.353826	4.76E-05

Step 4 –National CPI Data with National PPI Data Compared with RS Means Historic Index

Step 4 combined the two indices to determine if the previous steps result in a reasonably representative model. The selected PPI variables were included because they are related to stormwater BMP construction bid items, while the identified CPI variables are both related to stormwater BMP construction and are determined for key regional locations. CPI variables that were shown to vary similarly to the Historic RS Means index such as fuels and utilities, energy, and diesel fuel are also items that represent construction activity necessary to implement most BMPs.

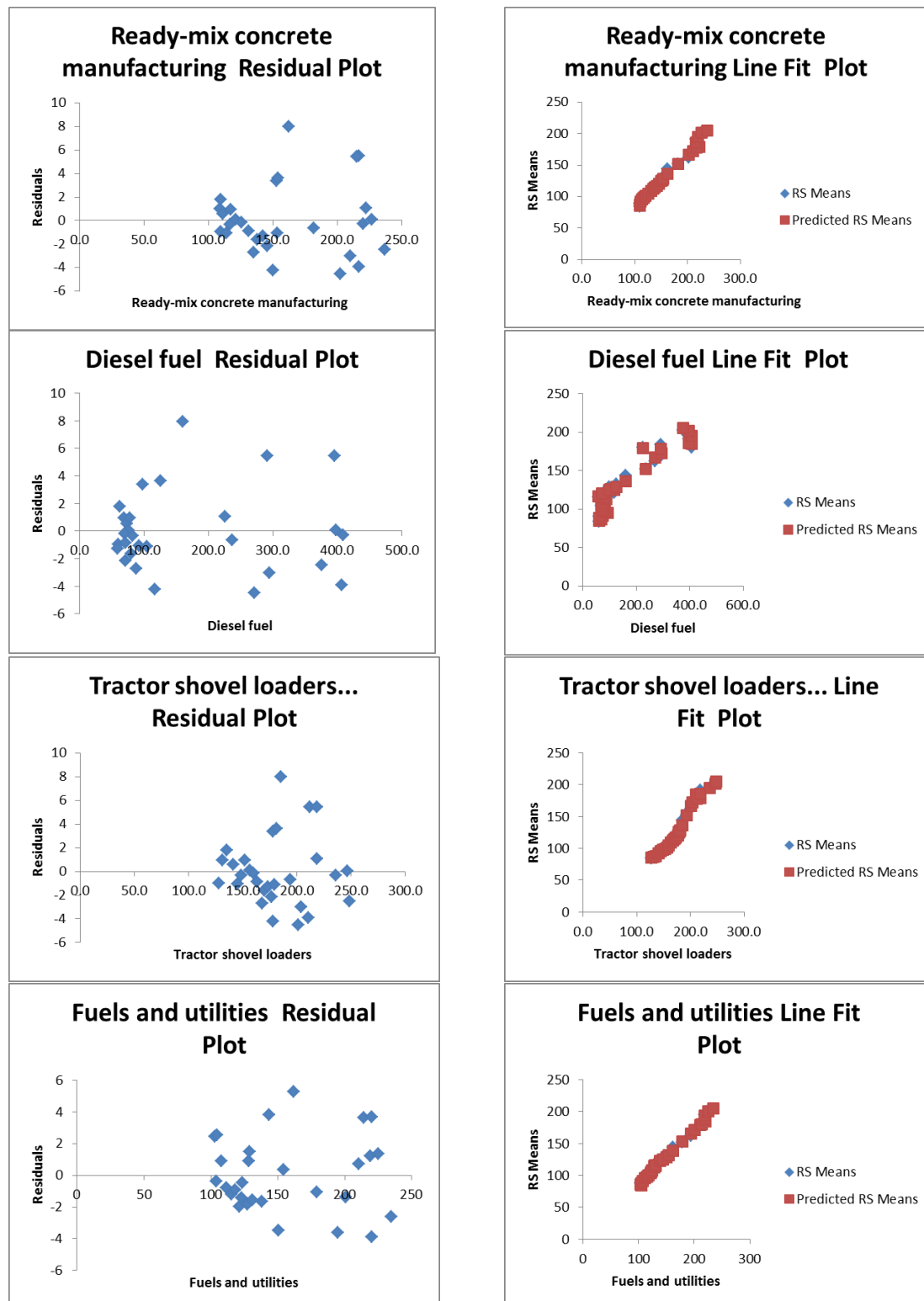


Figure 2-2. Residual and line fit plots for the model using ready-mix concrete, diesel fuel, and tractor shovel loaders.

The same process applied in Step 3 for the PPI data was completed for the CPI data. Again, the r-squared value, the *p*-value, residuals plot, and line fit plot were examined iteratively to evaluate the ability of the predicted data to represent the RS Means indices. This step was completed to select the most appropriate variables. Table 2-6 contains the *p*-values associated with the correlation of the selected CPI and PPI variables. The model developed varied from RS Means values by +/- 4%. Comparison information is presented below in Table 2-6, Table 2-7 and Figure 2-3.

Table 2-6. Coefficients and P-values for the Selected Cost Model

<i>Variable</i>	<i>Coefficients</i>	<i>P-value</i>
Intercept	-19.4284	0.00037
Ready-mix concrete manufacturing	0.113389	0.05448
Tractor shovel loaders	0.325493	1.13E-05
Energy	0.096662	0.13369
Fuels and utilities	0.398318	0.02372

Table 2-7. Statistics for the Cost Model

<i>Comparison Statistics</i>	
Multiple R	0.998145
R Square	0.996294
Adjusted R Square	0.995676
F-statistic	$F_{1,29} = 1612.9, p < .0001$

The final regionalized cost model is shown in equation 1.

$$\begin{aligned}
 \text{Cost Index}_{\text{year } n} = & -19.4 + (0.113 * \text{Ready mix concrete}_{\text{year } n}) + (0.325 * \\
 & \text{Tractor shovel loader}_{\text{year } n}) + \\
 & (0.097 * \text{Energy}_{\text{year } n}) + (0.398 * \text{Fuels and utilities}_{\text{year } n})
 \end{aligned}
 \tag{Eqn. 1}$$

Figure 2-4 illustrates how the model compared with the annual RS Means Historic Index. Data were plotted for 1986 to 2014 when the annual RS Means Historic Index is reported.

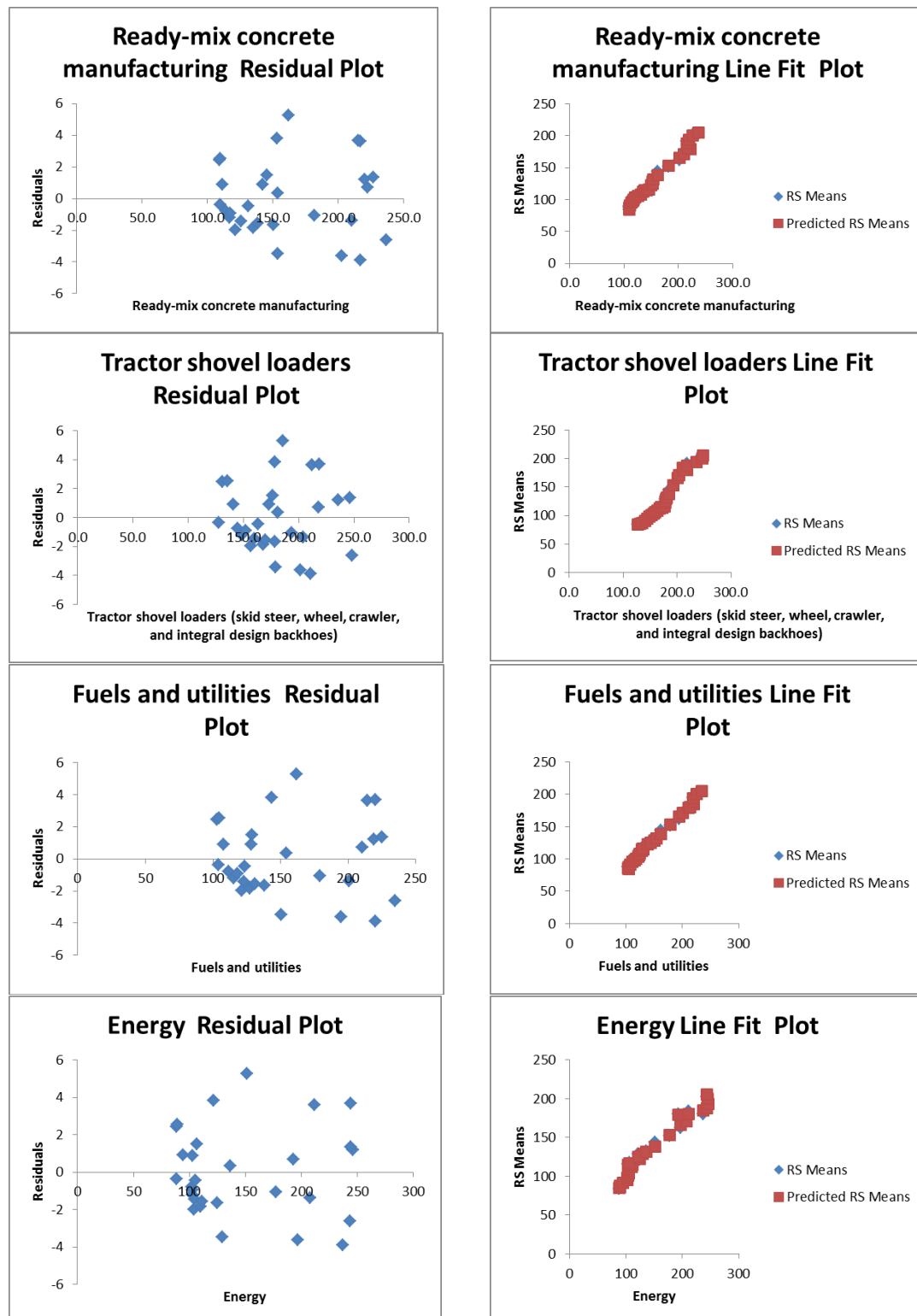


Figure 2-3. Residual and line fit plots for the cost model variables.

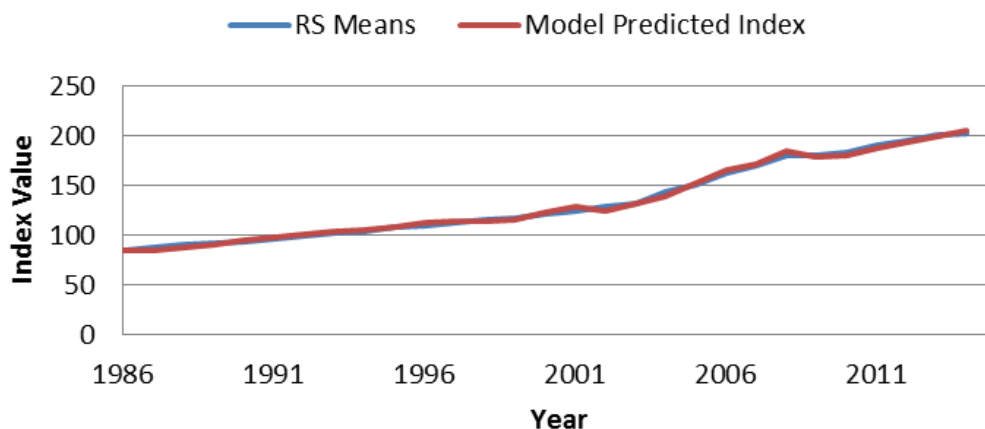


Figure 2-4. Comparison of RS Means and model predicted indices.

Step 5 – Consideration of the Use of Monthly Indices

The monthly values from the BLS data were inserted into Equation 1 to understand if the greater time resolution had similar results. Because the annual index is an average of the monthly indices, there is an expectation that the monthly indices will also do well in having similar variability to the RS Means Historic Index values. To test this concept, the monthly indices predicted by the model were compared to the annual indices predicted by the model. The average monthly model output was $\pm 4\%$ of the annual model and was less than $\pm 6\%$ different from the annual RS Means Historic Index data. These results suggest that use of the monthly or annual data within the model is comparable to annual RS Means data. However, using monthly data can imply a precision to the model that may not exist.

Step 6 – Creating Regional Multipliers for Application to the SWC

In addition to being able to adjust costs to account for annual cost changes and automated updates in future years, the application of the CPI data within the model can be also used to create regional multipliers that represent the recognized cost differences throughout the United States. To complete this, regional BLS CPI data were downloaded for all major urban areas available. Regional CPI data were entered in the model along with selected PPI data to determine annual indices that vary similarly to the annual RS Means Historic Index for each major urban area. Figure 2-5 illustrates how the cost model indices at the BLS urban area locations around the United States compare to the national average cost model (dashed line). Results were expected based on notable cost of living cost differences by region. For example, Honolulu and San Francisco appear to exhibit the highest cost indices, whereas Houston and Miami have the lowest cost indices.

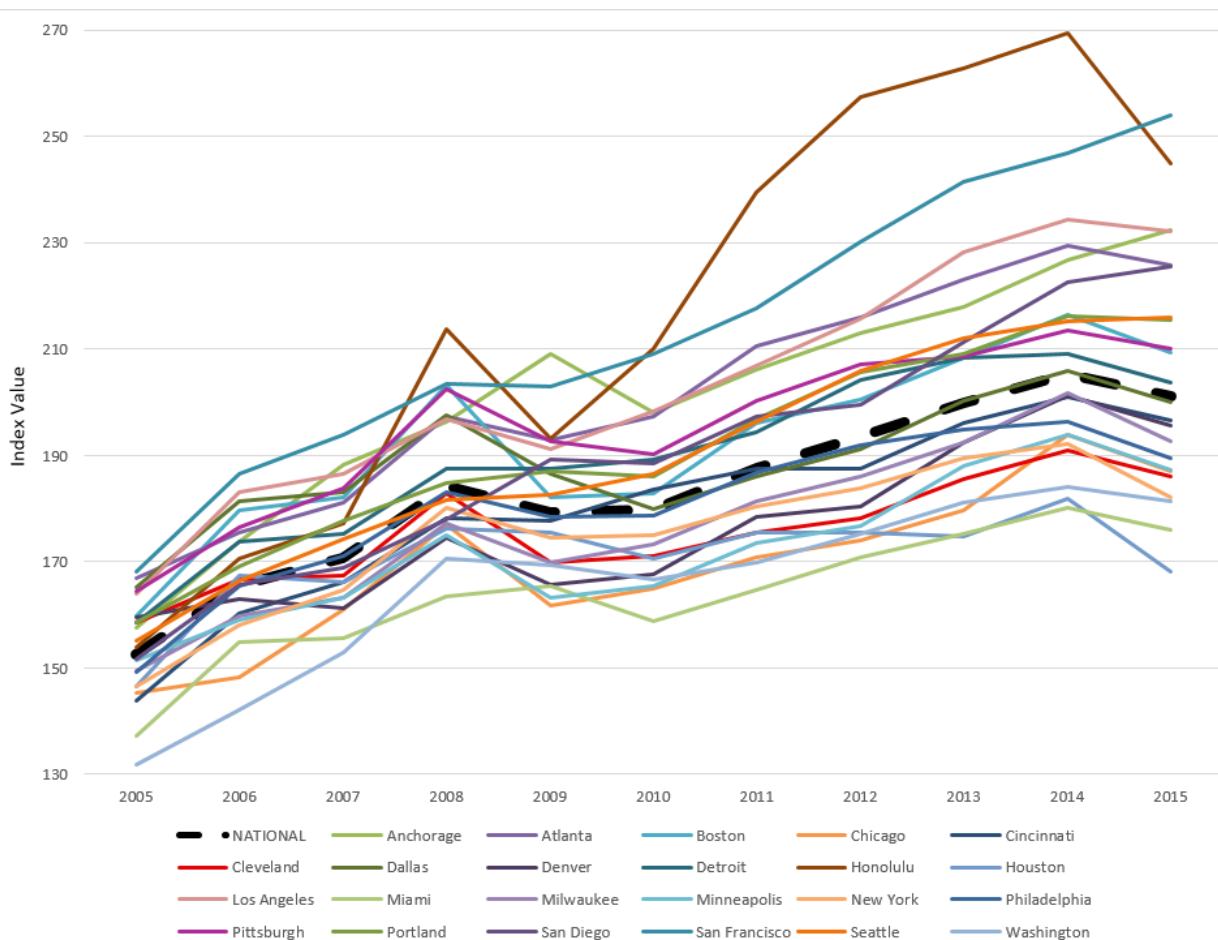


Figure 2-5. Comparison of regional cost indices around the United States with the national average.

In order to create a regional multiplier, an index was calculated using the modeled values for each city and then dividing by the national index to normalize to the national average. This was done for each year. Figure 2-6 shows the results for years 2005 – 2015 (annual data). A regional multiplier greater than one indicates that regional cost index for that city is higher than the national average. A regional multiplier less than one indicates that the cost index in that location is lower than the national average. Comparison of the predicted 2014 regional BLS annual cost multiplier using the cost model with 2014 annual regional RS Means indices are shown in Figure 2-7.

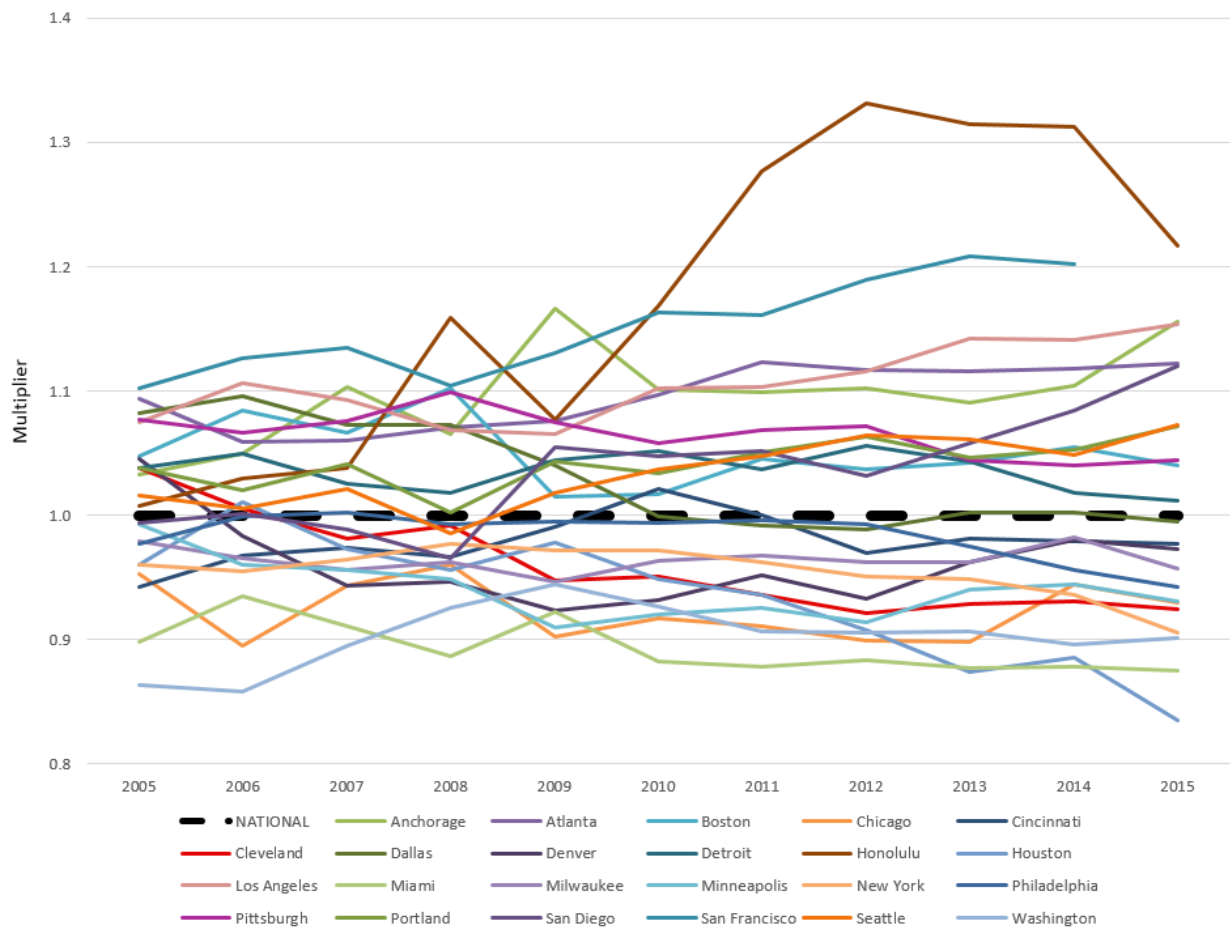


Figure 2-6. Modeled cost multipliers of US urban regions.

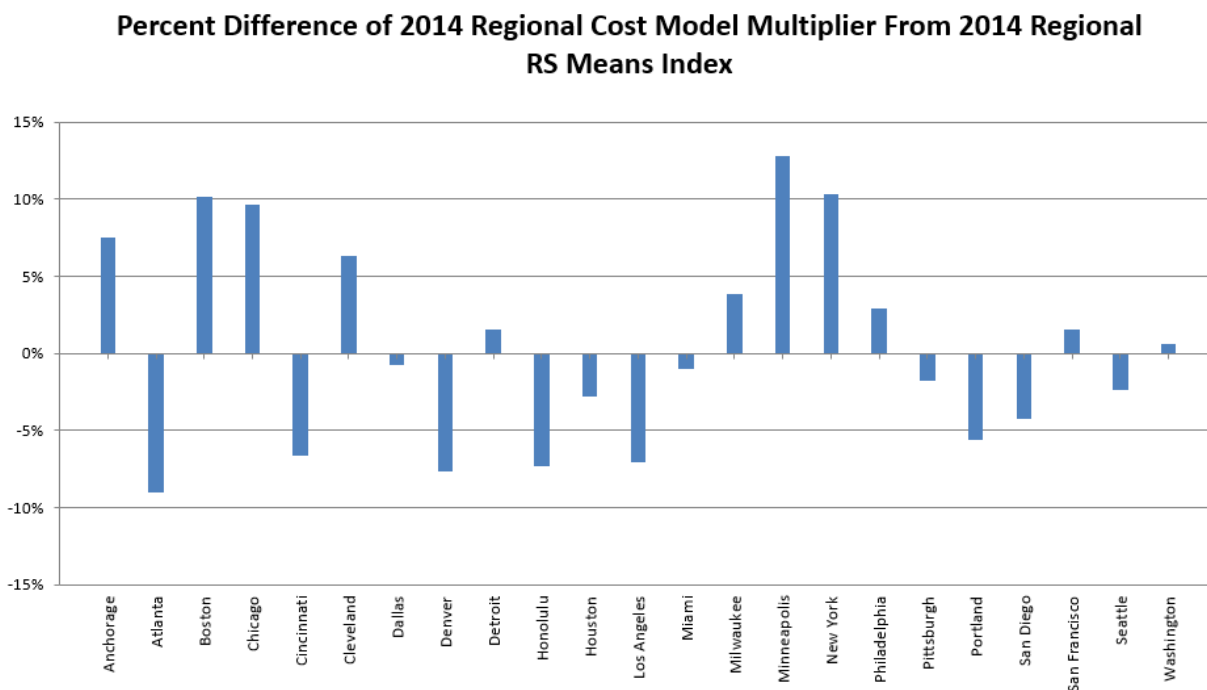


Figure 2-7. Comparison of the cost model regional multipliers with RS Means regional indices.

Step 7 – Validation

In order to validate the model, data for five regional case studies (Dillwyn, VA, Chesterland, OH, Mission, KS, and two in Portland, OR) were used to compare actual costs with the predicted SWC costs adjusted by applying the regional cost multiplier. Three of the five cost estimates were within the range estimated by the calculator. Of the two that were not well predicted, one was under-predicted by 38% (Mission, KS), and one was over-predicted by 37% (Portland, OR). There are potentially many causes for the differences. This analysis did not complete a detailed design assessment to determine what may have caused these differences for these locations. Although there are many factors that influence the cost of actual projects, such as those that were highlighted in TO 019 (PR-ORD-14-00308), it is expected that the SWC cost model with regional BLS-based cost indices will provide a reasonable range of cost estimates for stormwater construction and operation and maintenance costs.

The above seven steps result in an effective approach to develop multipliers based on BLS data that represent a regionalized costing approach. This approach was applied to the cost ranges previously developed in order to customize costs for areas near one of the 20 BLS regional centers. For areas located more than 100 miles from a BLS regional center, a national multiplier of 1 is recommended. This cost regionalization approach has been programmed into the SWC to reliably and electronically acquire the necessary BLS data, compute regional cost multipliers based on the location of the study area selected in the SWC. Study area locations that are more than 100-miles from the nearest BLS center default to the National multiplier, however the user is given the option of either selecting one of the three nearest BLS regional centers or specifying their own multiplier.

2.3 Adjusting for Inflation

The itemized unit costs used in developing the cost curves for all the LID controls were 2014 unit costs. To adjust cost estimates for inflation that may have occurred since the curves were first developed, the SWC applies an inflation adjustment factor computed using National BLS data derived from CPI and PPI variables for 2014 and comparing it to the value of the same index computed using CPI and PPI variables for the current year. The inflation factor is calculated by dividing the current National Index by the 2014 National Index. The companion Cost Estimation Excel Spreadsheet Tool developed under TO 0019 (PR-ORD-14-00308) and updated under the current TO, contains a detailed implementation of this computation. Once computed, the inflation adjustment factor is then applied to the regionally adjusted cost estimate to obtain the final cost range.

SECTION 3. Implementation

This section provides a brief description of the algorithms and software development process used to implement the cost estimation methodology discussed in SECTION 2. The technical description of the software development process is necessarily brief since the product under development was relatively small and was completed by a very small team.

3.1 Cost Estimation Algorithm

As previously stated the cost curves developed under TO 0019 (PR-ORD-14-00308) are the basis for estimates in the SWC. The cost curves are implemented using regression equations computed from the curves. Next, the cost regionalization and inflation adjustment multipliers are computed using the following steps:

Step 1 – Determine User Location and BLS Regional Center to Apply

On the **Location Tab** of the SWC the user either searches with an address or clicks on the map to indicate a desired location. The SWC obtains the coordinates for the location specified by the user. Using these coordinates, the SWC calculates distances to all 20 BLS Regional Centers and identifies the nearest 3 regional centers for display in the **Cost Region** combo box in the **LID Controls Tab** of the SWC. The nearest location is selected as the default for regionalization purposes. If the location of the nearest BLS Regional Center is further than 100 miles away a national multiplier of 1 is selected as the default. The BLS centers used in the SWC as shown in Table 3-1.

Step 2 – Determine latest year for which BLS Data is available

Using the system date and time at the time of user input in Step 1, the SWC retrieves BLS data for the latest year on record.

Step 3 – Obtain BLS Data variables for Cost Regionalization Regression Model (Model)

Using the BLS Regional Center from Step 1 (e.g., Anchorage, AK) and the model year from Step 2 (e.g., 2015), the SWC queries the BLS API and retrieves the values for the variables in the regionalization model as shown Table 3-2. More information on the BLS API can be found at <http://www.bls.gov/developers/>.

Table 3-1. BLS Regional Centers

BLS Series ID	State	Regional Center Name	2015 Computed Regional Multiplier	Latitude	Longitude
0000	NA	NATIONAL	1.000	0	0
A427	AK	Anchorage	1.000	61.16792	-149.847
A319	GA	Atlanta	1.105	33.8241	-84.3319
A103	MA	Boston	0.928	42.37313	-71.1407
A207	IL	Chicago	1.132	41.82713	-87.8954
A213	OH	Cincinnati	1.075	39.18551	-84.462
A210	OH	Cleveland	0.979	41.44364	-81.6054
A316	TX	Dallas	0.930	36.06054	-102.515
A433	CO	Denver	0.861	39.71077	-104.955
A208	MI	Detroit	0.980	42.48975	-83.2272
A426	HI	Honolulu	1.018	21.36456	-157.94
A318	TX	Houston	1.312	29.78431	-95.3935
A421	CA	Los Angeles	0.886	33.98267	-118.104
A320	FL	Miami	1.141	26.17562	-80.2314
A212	WI	Milwaukee	0.878	43.05567	-88.1005
A211	MN	Minneapolis	0.982	44.97816	-93.2798
A101	NY	New York	1.006	40.71836	-73.9702
A102	PA	Philadelphia	1.158	39.97333	-75.2982
A104	PA	Pittsburgh	1.121	40.45696	-79.951
A425	OR	Portland	1.040	45.5204	-122.651
A424	CA	San Diego	1.053	32.92873	-117.129
A422	CA	San Francisco	1.084	37.69012	-122.128
A423	WA	Seattle	1.202	47.46841	-122.275
A311	DC	Washington	1.049	38.89739	-77.1897

Table 3-2. National BLS Variables and Model Coefficients

BLS Variable	Model Coefficients	Model Year Values (2015)	
		Anchorage	National
Ready-mix concrete manufacturing	0.113	NA – use national	247.6
Tractor shovel loaders (skid steer, wheel, crawler, and integral design backhoes)	0.325	NA – use national	249.7
Energy	0.096	260.622	202.895
Fuels and utilities	0.398	294.650	230.129

NA – Not Applicable

Step 4 – Compute Cost Regionalization Factor

If the default location from Step 1 was National and the user does not select another regional center in the LID Controls Tab or provide their own factor, the SWC skips this step and proceeds with a cost regionalization multiplier of 1.

If the user selected one of the 20 regional centers, e.g., Anchorage, then using the data obtained from the BLS API in Step 3, the SWC computes the cost regionalization factor using the cost regionalization regression model from Step 4 of Section 2.2

Step 5 – Apply Cost Regionalization Factor to Lower and Upper Ranges Calculated by SWC

Using the cost regionalization factor from Step 4, the upper and lower ranges of every LID control cost calculated is multiplied by the cost regionalization factor to obtain a spatially-adjusted cost range.

Step 6 – Apply Inflation Adjustment Factor Lower and Upper Ranges Calculated by SWC

Finally, an inflation adjustment factor is computed as described in Section 2.3 and applied to generate the final cost estimate range. This is the final value that is reported to the user.

3.2 Software Development Process

A rigorous software development process was not ideal for this effort due to the relatively small size of the product and the development team. Over the one-year course of the project, three minimum testable products (MTPs) were produced and released. This relatively few number of releases did not lend itself to a full Agile Scrum process as originally planned and documented in the Task Execution Plan (TEP). Therefore, a number of the software development process components such as two-week sprints and code reviews were eliminated in favor of a more tailored development process suitable for the scale and scope of the product under development.

3.3 Technology Choices

The project team explored various implementation approaches for adding the cost-estimation component to the existing SWC in a way that will allow the application to be migrated from the desktop to a web/mobile app in the future. The current version of the SWC is written in Microsoft™ C#.net (and requires users to download and install an executable file on their computers). Currently, only MS Windows is supported. Given the above context, possible implementation approaches for the cost-estimation component were:

- 1) *Design and code the cost component as a native C# module in the SWC to be potentially re-written or executed as a server process when the SWC is migrated to the web/mobile platform or compiled using cross-platform frameworks for deployment on mobile devices*
- 2) *Design and code the cost component as a JavaScript/HTML5 component similar to the current Bing Maps component in the SWC to minimize re-writing when the SWC is migrated to the web/mobile platform.*

Discussion of the strengths and weaknesses of these two approaches follow.

3.3.1 Approach #1: Native C# Approach

Since the most of the code of the current SWC is written in C# and will need to be translated, the cost component could be written in C# and translated along with the rest of the code base when the migration to mobile occurs. Also, projects like [Xamarin™](#), [Monocross™](#) and [Mono Develop™](#) are working on frameworks that allow native C# code to be compiled for use on multiple platforms including Linux, Mac OS X, iOS, Android and Windows. While the stability and future widespread adoption of these projects remain in question, using C# still offers a potentially viable path to mobile with the added advantage that the code base for the mobile and desktop versions can be maintained in the same language, eliminating the need for future developers to be competent in multiple languages. The main disadvantage of this approach is that the maturity and long term viability of the frameworks needed to support cross-platform mobile and desktop development in C# lags behind that of the HTML5/JavaScript approach which is discussed next.

3.3.2 Approach #2: HTML5 / JavaScript Approach

Implementing the cost-estimation component in JavaScript/HTML5 allows the new code to be potentially integrated directly into a future web app (and hybrid mobile app built with HTML5/JavaScript) with little or no modification. This approach is consistent with the current architecture of the SWC since it is the same approach that is used to add Bing Map (Virtual Earth) support to the SWC for displaying the embedded map used to locate the study area, show soils layers, topography, and rain gage locations. The project team chose this as the preferred approach for implementation. Internally, all the inputs, once collected are then passed to internal JavaScript code and the results are passed back to the native C# main form for display to the user. Using this approach, most of the core logic for the cost-component was implemented in JavaScript and is therefore useable in a future JavaScript/HTML5 web/hybrid app version of the SWC designed for mobile devices if future developers decide to use it.

3.3.3 Development Environment

Development of the product began with Microsoft™ Windows 7 and Visual Studio 2015 as the primary development platforms. Development was later completed on Microsoft™ Windows 10 and Visual Studio 2015. A separate Installaware™ project was used to build an installable executable for deployment.

3.3.4 Deployment Environments

The original predominant platform at the start of the project was MS Windows 7. Windows 10 was, however, released while the project was under development and has now become the new primary deployment platform. This is prudent since the majority of the users of the SWC will likely be using Windows 10 shortly before or after the SWC update is released. All MTPs are also usable on Windows 7 and 8 required by the TO.

3.4 Data validation and verification

Consistent with the EPA's quality assurance (QA) requirements, the EPA-approved Quality Assurance Project Plan (QAPP) and the TEP describe the procedures that facilitate selection of appropriate data and information to support the goals and objectives of this TO. Data validation and verification procedures for this project are documented in the TO 026 QAPP, TEP and the Final QA/QC Report. These data validation and verification procedures are primarily based on multiple levels of reviews of the approaches and methodologies developed, testing of the software produced with real world data via case studies, and the use of well-documented data sources, including RS Means for unit costs, data from the BLS for cost regionalization and inflation, and actual costs from constructed projects. Refer to the QAPP, TEP and the Final QA/QC reports for detailed discussion on quality.

SECTION 4. Results and Outcomes

The outcome of this TO is an updated SWC that is now capable of producing estimates of probable construction and maintenance costs for all supported LID controls. The SWC now produces a tabular representation of estimates of probable capital costs (see Figure 4-1), as well as a graphical representation (see Figure 4-2). Similarly, estimates of tabular (see Figure 4-3) and graphical (see Figure 4-4) representation for annual maintenance costs are also produced. Cost estimates are adjusted for inflation and represent dollar amounts for the current year.

Estimate of Probable Capital Costs								
Maintenance Costs Graphical View								
Cost By LID Control Type	Drainage Area %	Has Pre-trt?	Current Scenario (C) Area Treated 12.00 ac		Baseline Scenario (B) Area Treated 12.00 ac		Difference (C - B) Area Treated 0.00 ac	
	Current / Baseline	Current / Baseline	Low	High	Low	High	Low	High
Disconnection	NA / NA	No / No	\$0	\$0	\$0	\$0	\$0	\$0
Rainwater Harvesting	15 / NA	No / No	\$5,179	\$6,136	\$0	\$0	\$5,179	\$6,136
Rain Gardens	20 / NA	No / No	\$36,466	\$75,498	\$0	\$0	\$36,466	\$75,498
Green Roofs	NA / NA	No / No	\$0	\$0	\$0	\$0	\$0	\$0
Street Planters	NA / NA	No / No	\$0	\$0	\$0	\$0	\$0	\$0
Infiltration Basins	25 / NA	No / No	\$54,069	\$144,553	\$0	\$0	\$54,069	\$144,553
Permeable Pavement	40 / NA	No / No	\$316,171	\$422,010	\$0	\$0	\$316,171	\$422,010
Note: site complexity variables that affect cost shown below:								
Current Scenario					Baseline Scenario			
Dev. Type Re-development					Re-development			
Site Suitability Poor					Poor			
Topography Mod. Steep (10% Slope)					Mod. Steep (10% Slope)			
Soil Type B					B			
Cost Region Atlanta (56 miles) 1.12					Atlanta (56 miles) 1.12			

Figure 4-1. Tabular example of the calculator's estimate of capital costs.

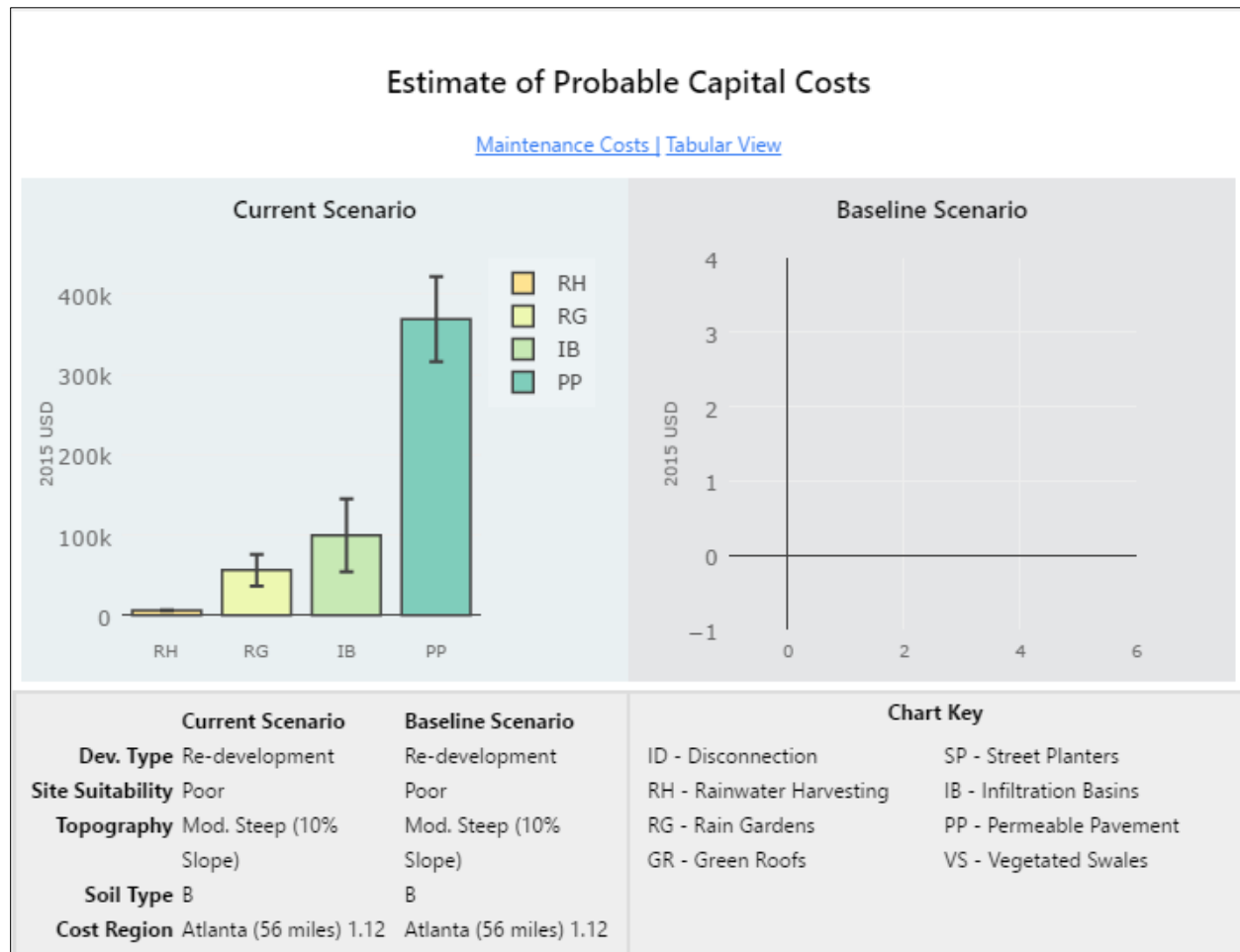


Figure 4-2. Graphical example of the calculator's estimate of capital costs.

Estimate of Probable Maintenance Costs						
Capital Costs Graphical View						
Cost By LID Control Type	Current Scenario (C)		Baseline Scenario (B)		Difference (C - B)	
	Low	High	Low	High	Low	High
Disconnection	\$0	\$0	\$0	\$0	\$0	\$0
Rainwater Harvesting	\$165	\$396	\$0	\$0	\$165	\$396
Rain Gardens	\$1,394	\$33,708	\$0	\$0	\$1,394	\$33,708
Green Roofs	\$0	\$0	\$0	\$0	\$0	\$0
Street Planters	\$0	\$0	\$0	\$0	\$0	\$0
Infiltration Basins	\$2,864	\$104,026	\$0	\$0	\$2,864	\$104,026
Permeable Pavement	\$3,747	\$20,465	\$0	\$0	\$3,747	\$20,465

Note: site complexity variables that affect cost shown below:

Current Scenario		Baseline Scenario	
Dev. Type	Re-development	Dev. Type	Re-development
Site Suitability	Poor	Site Suitability	Poor
Topography	Mod. Steep (10% Slope)	Topography	Mod. Steep (10% Slope)
Soil Type	B	Soil Type	B
Cost Region	Atlanta (56 miles) 1.12	Cost Region	Atlanta (56 miles) 1.12

Figure 4-3. Tabular example of the calculator's estimate of maintenance costs.

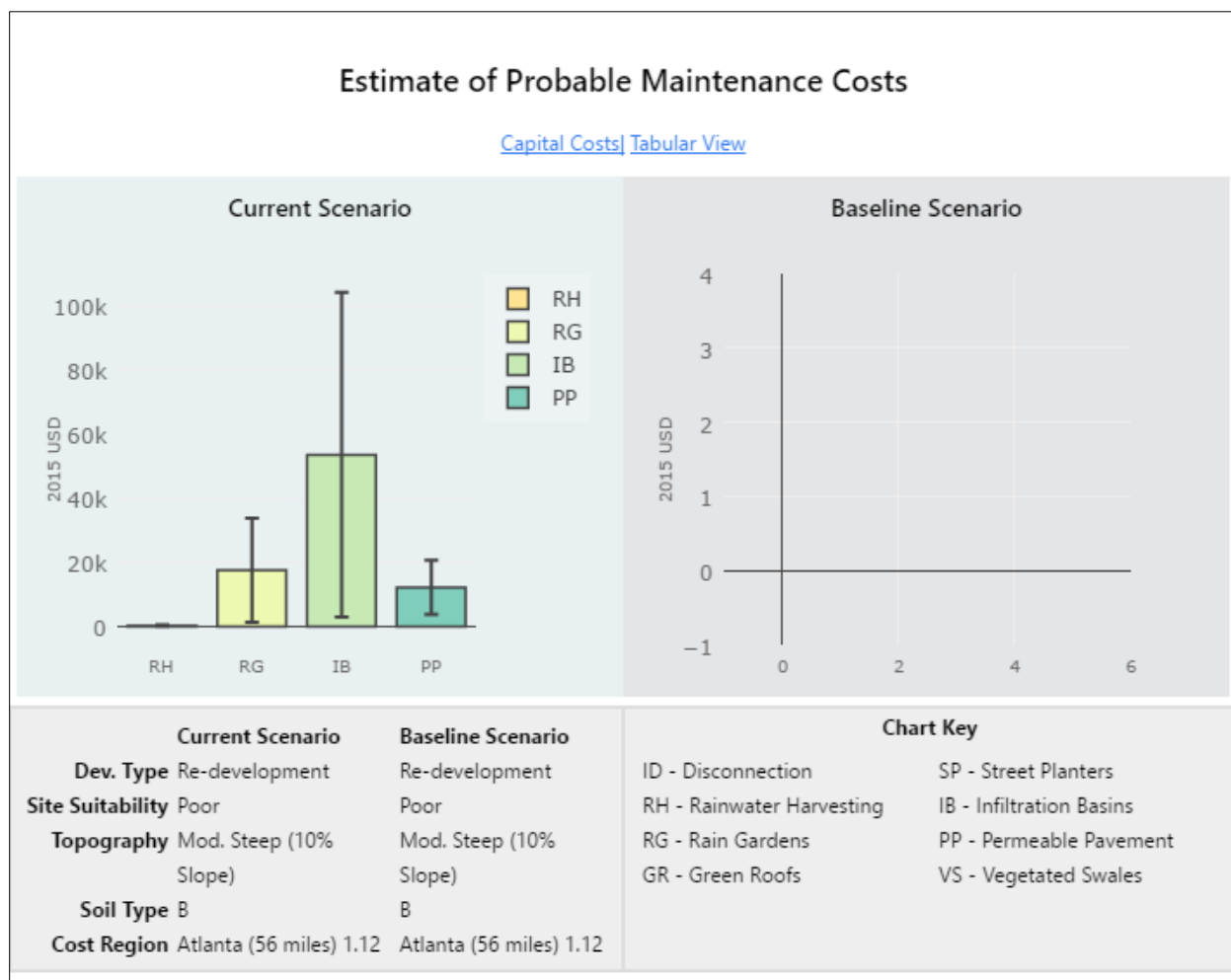


Figure 4-4. Graphical example of the calculator's estimate of maintenance costs.

A secondary outcome of this TO is the development of a cost regionalization method based on BLS data that is targeted to LID construction costs. The cost regionalization approach is implemented in the SWC in a way that requires little maintenance (unless BLS API endpoints change or project requirements change).

In summary, this TO 026 has resulted in the development of a dynamic target cost regionalization method and an expanded SWC that provides estimates of probable capital and maintenance costs with minimal inputs from the user. Highlights of the features of the updated SWC include:

- Dynamically obtains BLS data based on the location of the study area to compute a regionalization multiplier
- Dynamically applies an inflation adjustment factor computed using dynamically obtained BLS data and the current year at the time of execution
- Produces cost estimates that account for development type (i.e., new- versus re-development)
- Accounts for construction feasibility via site suitability options (poor, moderate or excellent)
- Produces tabular results that show estimates for two scenarios side-by-side as well as the difference between the scenarios

- Produces a graphical summary of the results using dynamic vector graphs. Main features of the charts include:
 - Bar charts include error bars that represent the range of each cost estimate
 - Provides numeric display of the cost range when users hover over each bar
 - Allows bars representing individual LID control costs to be toggled on and off by clicking on items in the legend. This is useful when some LID costs are significantly higher or lower than the others.

SECTION 5. Case Study: Buckingham Elementary School, Dillwyn, Virginia

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 chosen was the redevelopment of the Buckingham Elementary School site in Dillwyn, Virginia (see Figure 5-1). The site encompasses a total of 10.5-acres and is 31% impervious. The LID controls implemented were rainwater harvesting, rain gardens, permeable pavement, bioinfiltration swales, bioretention cells, constructed wetlands, and impervious area disconnection. The LID practices are intended to help students interact with nature. Bioinfiltration swales and bioretention cells are included under the LID control “rain garden” for the rest of the case study as this is the name used for these LID controls within the SWC. The unit costs used for cost curve development include the components of these practices. Wetlands are not currently supported by the SWC. Therefore this case study will not include the constructed wetland practice.



Figure 5-1. Case study site – Buckingham Elementary School, Dillwyn, VA.

5.1 Site Description

The school was initially built in 1953 and over time had fallen into disrepair and was eventually abandoned. The site consisted of two separate buildings, a large parking lot bordering the roadway, two asphalt basketball courts and a playground in addition to field space. Prior to redevelopment, the site experienced moderate to acute flooding in the parking lot and in an adjacent field where poorly drained soils and flat topography inhibited drainage and infiltration.

The redevelopment initiative aimed to create a trail network with opportunities for students to interact with nature and to promote environmental sensitivity and stewardship. The LID stormwater plan complemented this initiative by including the constructed wetland, bioinfiltration swales, permeable pavement, and rainwater harvesting cisterns that store water for supporting irrigation for a school garden.

General site characteristics include Type C soils with moderately high runoff potential. The soil at the site was estimated to have an infiltration rate between 0.01 and 0.1 inches per hour. The topography of the site is moderately flat with slopes of approximately 5%. See Figure 5-2 for input tabs of the SWC. Table 5-1 provides the inputs for the SWC in tabular form.

Table 5-1. Buckingham Elementary Case Study SWC Input Variables

Variable	Value
Total Area (acres)	10.5
Estimated Imperviousness (%)	31.0
Site Soils	Type C
Soil Drainage (inches/hour)	0.01
Topography	moderately flat

In order to verify the SWC cost estimation procedure, the portion of the site area draining to each LID practice was estimated. The size of each practice was estimated based on measurements made on Google Earth. Table 5-2 presents the percent of impervious area treated by each LID control. These are the inputs used for the “LID Controls” tab of the SWC. Based on these inputs, the SWC sizes the LID control.

Table 5-2. LID Control Inputs

Practice	Percent of Impervious Area Treated (%)
Disconnection	5
Rainwater harvesting	19
Rain gardens	5
Permeable pavement	5

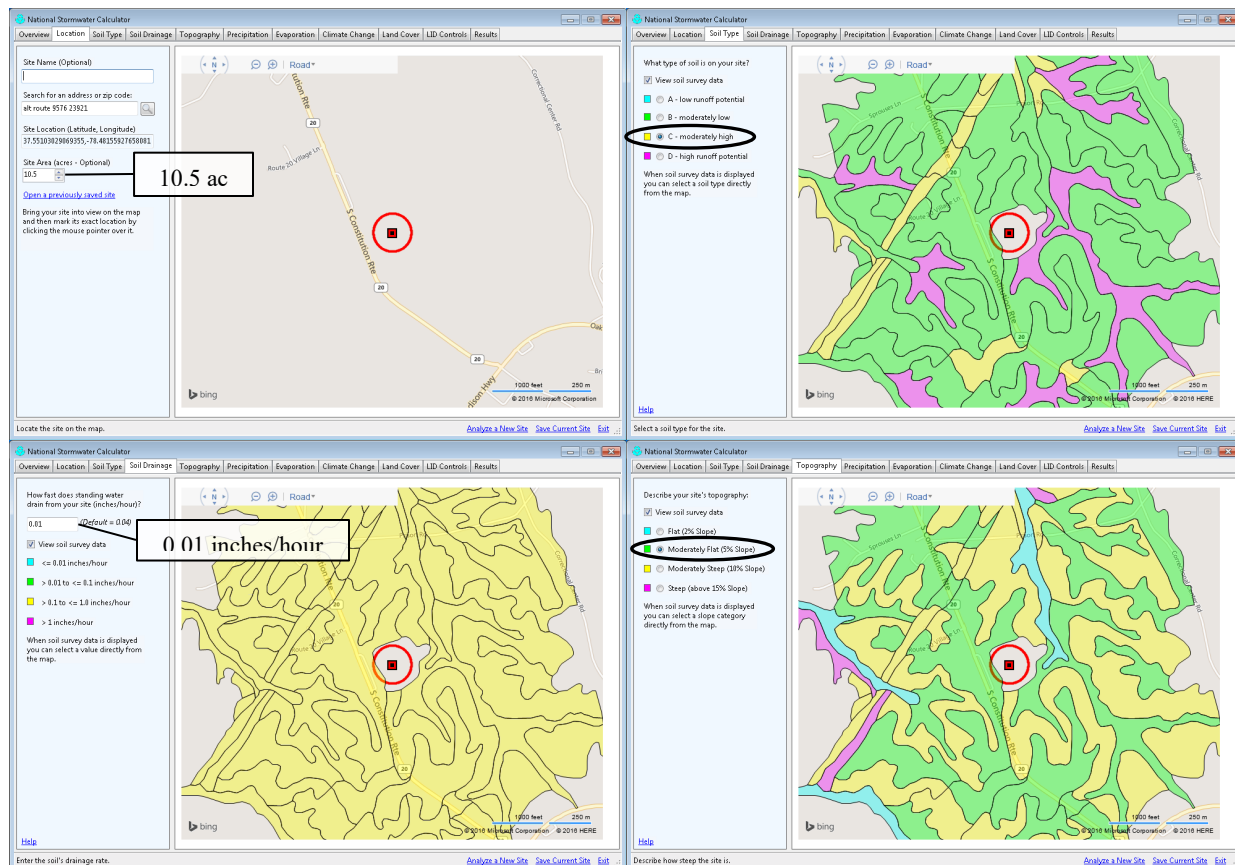


Figure 5-2. Depiction of Buckingham Elementary case study SWC input screens.

5.2 Cost Estimation

The cost data and estimation procedure uses the information collected in other SWC input fields to determine which design scenario (simple, typical, or complex) should be applied to the project site. The inputs from the SWC that influence the design scenario include the following:

- New development vs. re-development
- Pretreatment vs. no pretreatment
- Site suitability (poor, moderate, excellent)
- Topography (flat, moderately flat, moderately steep, steep)
- Soil Type (A, B, C, or D)

The Buckingham Elementary Case Study has the following characteristics which were used to determine the design scenario:

- Re-development
- No pretreatment
- Poor site suitability
- Moderately flat topography
- Soil type B

Based on the inputs, the design scenario is considered a “typical” scenario. Table 5-3 provides the capital and maintenance costs provided by the SWC, as well as the actual capital cost of the project for comparison.

Table 5-3. Case Study – LID Control Cost Summary

LID Control	Capital Cost Range	Maintenance Cost Range
Disconnection	\$83,500 – 107,600	\$1,100 – 1,700
Rain Harvesting	\$29,600 – 40,873	\$3,400 – 8,200
Rain Gardens	\$5,375 – 10,412	\$100 – 1,800
Permeable Pavement	\$107,300 – 143,400	\$1,300 – 6,900
Total Cost (2015 \$)	\$225,700 – 302,200	\$5,900 – 18,500
Actual Project Cost (2014\$)	\$268,662	Not Available

The actual project cost of \$268,662 fell within the SWC’s predicted range of \$225,700 to \$302,200. The results of this exercise demonstrate that although the SWC and SWC cost estimation procedure have limitations which may not accommodate all design scenarios, the development of planning level cost scenarios do provide an adequate understanding of costs for this case study.

SECTION 6. Conclusion

This document discusses the development and implementation of a cost estimation procedure for LID controls for inclusion in the SWC. Adding cost estimation capabilities to the SWC is anticipated to further enhance the popularity of the SWC and promote the use of the calculator by new converts. The cost estimation methodology that has been developed matches the ease of use of the current version of the SWC. The approach is based on the use of unit cost information to create curves for varying complexities of LID control implementation previously developed under TO 019 (PR-ORD-14-00308). An approach for regionalization of costs across the nation was developed using data from BLS. The regionalization approach allows the calculator to account for regional differences in LID control implementation costs around the Country. The calculator dynamically obtains BLS data via the BLS API and computes the regionalization multiplier for the user. The output of the updated SWC are both tabular and graphical outputs representing estimates of probable capital and annual maintenance costs. To verify the cost estimation methodology and the updated SWC, a case study including cost information for a site in Dillwyn, Virginia, with known LID implementation costs was used to compare to estimates obtained from the SWC. The results obtained were found to reasonably bracket the estimate from the site.

To support EPA’s intentions to eventually deploy the SWC as a web application, the majority of the code for the cost module of the SWC was written using a web-friendly approach based on the use of JavaScript and HTML5. To stay relevant, periodic maintenance of the code and cost estimation framework implemented in the updated SWC will be required. A cost estimation framework spreadsheet developed as part of TO 019 (PR-ORD-14-00308) for producing cost curves was further enhanced during this effort to automatically produce regression equations from the cost curves which can then be easily copied and integrated into the code for future updates of the SWC. This should greatly aid in future maintenance of the SWC.

SECTION 7. REFERENCES

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SECTION 8. Appendix A – User Guide

(Submitted under separate cover to maintain page numbering and formatting of original User's Guide)