# Constructing Stormwater Retrofits in Maryland: Challenges & Recommendations for Cost Estimation

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## List of Acronyms

| | |
|---|---|
| BMP | Best Management Practice |
| CBT | Chesapeake Bay Trust |
| CSN | Chesapeake Stormwater Network |
| DNR | Maryland Department of Natural Resources |
| GI | Green Infrastructure |
| MS4 | Municipal Separate Storm Sewer System |
| NFWF | National Fish and Wildlife Foundation |
| NPDES | National Pollutant Discharge Elimination System |
| TMDL | Total Maximum Daily Load |
| WQv | Water Quality Volume |

## Executive Summary

Maryland communities are poised to spend millions on stormwater retrofit implementation to meet stormwater permit and Chesapeake Bay total maximum daily load (TMDL) requirements. The available information on retrofit costs is highly variable and does not reflect the enormous amount of implementation that has occurred over the past five years. Reliable information is needed on the true costs of implementing stormwater retrofits, so that communities can better plan and budget for them and funders can direct their limited funds towards the most cost-effective practices.

The goal of this study was to compile and analyze recent data on actual construction costs for stormwater retrofits across the state to develop a white paper that helps to fill the gaps in knowledge on stormwater retrofit costs. The following research questions were identified for this study:

- What are the design and construction costs of stormwater retrofits?
- How do these costs vary with BMP type, location, site conditions, or design features?
- Which BMPs are most cost-effective for nutrient and sediment removal?
- How do the final construction costs compare with the initial estimated project costs?
- What are some lessons learned and challenges associated with these projects that affected the cost, timeline, and ultimate success of the project?

The Center for Watershed Protection compiled data from the Maryland Department of Natural Resources (DNR) on 584 stormwater retrofit projects constructed by 41 different partners over the past seven years in Maryland. The Center reached out to these partners to collect additional information on the constructed retrofits and their costs. Only a limited number of partners provided the requested information and after evaluating the data, a total of 46 retrofits were identified for analysis based on completeness. Basic descriptive statistics and plot as well as linear regression, ANOVA analysis, and the Tukey Honest Significant Difference test were completed using the statistical program R. Due to the limited dataset, the Center also conducted supplemental interviews with grantees and statistical analysis of data on bioretention costs collected by the Chesapeake Stormwater Network in 2012.

The most apparent finding of this study was that the data collected were not sufficient to answer all of the research questions. In particular, there were not

enough retrofits for which complete responses were provided to be able to draw conclusions from the analysis on how specific factors, such as design features or permit required, affected retrofit costs. In addition, most of the data collected were for bioretention practices, which limited the ability to compare costs and cost-effectiveness across retrofit types.

Key findings from the analysis include:

- On average, bioretention is more expensive on a per unit basis ($/cf of water quality volume (WQv)) than ponds and wetlands. However, the unit cost is highly variable, due to economies of scale (e.g., larger bioretention practices are more cost-effective than smaller bioretention practices).
- WQv is the single most reliable predictor of practice cost, accounting for 53% of the variability in cost.
- For bioretention practices, presence of an underdrain is generally associated with higher cost practices. This effect is not due to the cost of underdrain piping itself, but rather due to the underdrain as a predictor of the complexity of the practice design. In this dataset, for example, underdrains were used much more often for practices constructed in more urbanized counties.
- On average, it is about 2.7 times more expensive to construct BMPs in Maryland counties with high population densities than ones with low population densities.
- Design costs for bioretention are around 15% of the total cost, which is lower than those estimated by King and Hagan (2011). This difference may be due to potential underreporting of design costs to DNR, as their grant program primarily funds construction.

Given the difficulty with obtaining sufficient data for this study and based on the requests from grantees for a repository of cost data that can be used to improve cost estimates, the study concluded that improved tracking of retrofit cost data is needed. Specific recommendations for agencies funding retrofit implementation include:

- Consider evaluating grantee reporting systems/requirements and discuss what changes can better facilitate gathering consistent useful data for retrofit cost estimation
- In particular, add WQv as a required reporting element to facilitate better estimates of cost-effectiveness, impervious cover treated and pollutant removal

- Provide a simple tool or tools that lower-tech applicants and grantees can use estimate potential pollutant reductions, WQv and other commonly-required information as part of the funding program application resources
- Provide guidance and resources on retrofit cost estimation as part of the funding program application resources
- Summarize and analyze data on constructed retrofits funded through their programs on an annual basis to see what can be learned about how retrofit costs vary by BMP type, location, or other characteristics

The intent of these recommendations is that over time a more consistent dataset of costs and characteristics of constructed retrofits will become available to help answer the research questions identified in this study. Knowing the true cost of these practices will help funders to direct grants toward the most cost-effective ones and ensure that funding thresholds are appropriate given the expected cost. In addition, understanding the major factors affecting cost is an important step toward devising ways to reduce those costs. The research community can play a role in compiling this data across funding agencies and other implementers and evaluate this more robust dataset.

# Introduction

This paper summarizes the results of an analysis of costs associated with construction of stormwater retrofits in the State of Maryland. The Center for Watershed Protection, Inc. (the Center) collected data on recently constructed stormwater retrofit projects and interviewed recipients of grant funds who oversaw project implementation to learn more about the cost estimating process and challenges. The study findings have important implications for entities implementing stormwater retrofits and for funders of these projects. Recommendations are provided for granting agencies to ensure that the most relevant information needed to determine actual project costs is being collected, so that funding can be directed to the most cost-effective best management practices (BMPs).

## Background on the Need for Improved Stormwater Retrofit Cost Data

Maryland municipalities regulated under the National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) program are required to install stormwater management practices to treat 20% of their currently untreated impervious surfaces in each five-year permit cycle. In addition, they are responsible for specific reductions in nutrients and sediment from stormwater to meet the Chesapeake Bay Total Maximum Daily Load (TMDL) and other local TMDLs for pollutants such as nutrients, sediment, bacteria, and trash. Jurisdictions have been steadily working towards meeting these requirements by implementing a range of stormwater retrofit practices that capture, detain, infiltrate, and remove pollutants from runoff on properties with little to no existing stormwater treatment. These local governments are poised to spend millions more on additional stormwater retrofits over the next 10+ years to fully comply with MS4 and TMDL requirements.

Due to the enormous price tag associated with using stormwater retrofits to meet water quality requirements, Maryland communities need reliable information on the true costs of implementing these retrofits, so that they can better plan and budget for them, and so that they can direct their limited funds towards the practice types and situations that provide the most benefit.

Stormwater retrofits are much more expensive than non-urban best management practices (BMPs) or stormwater BMPs on new development sites (Schueler et al., 2007; Jones et al., 2010). This is due to the high cost of land in urban areas, the difficulty of shoehorning these practices in between existing structures, roads, parking lots, and utilities, and the presence of site constraints such as poor soils, all of which translate into added expense for design and construction. Because retrofit sites by definition have limited stormwater treatment, they are likely to be older and may have limited available information on the drainage system, underground utilities, or contamination status, which can lead to expensive surprises during the construction process.

Currently, the best available source of cost data for urban stormwater BMPs in Maryland is a 2011 University of Maryland study that provides planning-level life-cycle costs per impervious acre for approximately 30 BMPs (King & Hagan, 2011). The King and Hagan study compiled data from many sources that included national literature review, interviews with local jurisdiction staff, and cost estimates/bids as well as actual construction costs for both stormwater retrofits and new stormwater BMPs. The bulk of the data was from 2009 or older and the authors note the cost estimates are not suitable for assessing costs in specific situations because of the significant variability due to soil type, slope, landscape features, geography, project scale, and design features.

One of the few studies that focus specifically on stormwater retrofit costs was conducted by the Center when developing the Urban Stormwater Retrofit Practices Manual in 2007. This study confirms the cost variability identified by University of Maryland and found that, in many cases, construction costs were an order of magnitude different for the same volume of stormwater treated (Schueler et al. 2007). Most recent studies of stormwater BMP costs point back to a handful of sources (EPA, 1999; Brown & Schueler, 1997), and generally are not based on actual construction costs for stormwater retrofits.

Extensive implementation of stormwater retrofits in the Chesapeake Bay watershed over the past five years has provided a rich new source of data on actual constructed retrofit costs. In Maryland alone, municipalities have implemented enough stormwater retrofits to reduce more than 250,000 pounds of nitrogen[1]. This data holds immense potential to inform how communities budget for stormwater retrofits and to learn how different site, geographic, and design factors influence costs.

## Study Goals and Research Questions

The goal of this study was to compile and analyze recent data on actual construction costs for stormwater retrofits across the state to develop a white paper that helps to fill the gaps in knowledge on stormwater retrofit costs. The intent of the white paper was to help Maryland local governments, watershed organizations, and others who are implementing stormwater retrofits improve the reliability of cost estimates for their projects, and ultimately make these projects more successful. A secondary goal of the white paper was to help funding agencies direct their resources towards the most cost-effective

[1] http://baystat.maryland.gov/solutions-map/

stormwater retrofit practices. The following research questions were identified for this study:

- What are the design and construction costs of stormwater retrofits?
- How do these costs vary with BMP type, location, site conditions, or design features?
- Which BMPs are most cost-effective for nutrient and sediment removal?
- How do the final construction costs compare with the initial estimated project costs?
- What are some lessons learned and challenges associated with these projects that affected the cost, timeline, and ultimate success of the project?

## Data Collection

The Maryland Department of Natural Resources (DNR) provided a spreadsheet with 584 stormwater management projects constructed by 41 different partners over the past seven years in Maryland. These projects were funded through DNR's Chesapeake and Atlantic Coastal Bays Trust Fund grant program. Included in the spreadsheet was background information on each of the projects that was compiled from their respective proposals and final reports to DNR.

The Maryland DNR database of constructed projects contained useful information on each of the practices, including the location, name of the partner implementing the project, BMP type, and estimated annual nitrogen, phosphorus, and sediment removal. However, in terms of project costs, only the Trust Fund dollars and leveraged dollars were provided. The Center aimed to compile additional information from the grantees on the BMPs (e.g.., drainage area and water quality volume (WQv)) and their costs (e.g., a breakdown into pre-construction and construction costs) to address the research questions. Table 1 outlines the information that was provided to the Center by DNR at the start of this study.

| Table 1. Information Contained in DNR Project Database | |
|---|---|
| **Column Header** | **Description** |
| StateFiscalYear | Fiscal year during which the contract was awarded |
| ContractNumber | Contract number for the DNR-funded project |
| PartnerCD | Name of organization/DNR partner |
| PartnerType | County, municipality, non-profit, state, or university |
| ProjectTitle | Name of project |
| ProjectType | All entries were stormwater management projects |
| County | County in which the project was built |
| Description | Description of project |
| TrustFundDollars | Amount provided by the DNR Chesapeake and Atlantic Coastal Bays Trust Fund |
| TFLeveragedDollars | Amount provided by the partner as match |
| Watershed | HUC-8 code for watershed in which the project was built |
| Lat/Long | Latitude and Longitude of project location |
| LegislativeDistrict | Legislative district in which the project was built |

The spreadsheet was converted to a Google Sheets document to allow multiple respondents to work on the spreadsheet simultaneously, reducing the post-processing time. Using DNR-provided contact information for the grantees included in the spreadsheet, the Center contacted each partner to explain the purpose of the project and request the following additional information be added to the Google Sheets document:

- Total Cost
- Field Investigation Cost
- Design Cost
- Permitting Cost
- Construction Cost
- Construction Oversight Cost
- Field Investigation Labor
- Design Labor
- Permitting Labor
- Construction Labor
- Construction Oversight Labor
- Type of Retrofit
- Design-Build versus Separate Phases
- Land Owner
- Project Type
- ESC Permit Required?
- Other Permits Required
- Primary Land Use
- Utility Conflicts?
- Overall BMP Type
- BMP Group
- Design Variant
- Practice Name or Description
- Underdrain?
- Drainage Area (acres)
- Impervious Cover in Drainage Area (acres)
- Practice Surface Area (sf)
- Total Area Consumed by Practice (sf)
- WQv (cf)
- Design Storm Treated (inches)
- Additional Storage for Quantity Control (cf)
- Pretreatment Methods
- Overflow
- Unique Design Features
- Annual TN Reduction (lbs/yr)
- Annual TP Reduction (lbs/yr)
- Annual TSS Reduction (lbs/yr)
- Other Goals Met

Appendix A provides the instructions sent to the grantees with the request for information. These instructions expand upon each of the characteristics listed above. Several attempts were made to obtain the requested information from the grantees though email and telephone contacts that included offers to assist with compiling and manipulating the data into the requested format on behalf of the grantee. In the end, 17 of the 41 partners contacted entered new data into the spreadsheet, providing data for 206 of the 584 projects.

## Data Analysis

The study analysis focused primarily on the DNR data collected as a part of this project. However, due to the limited number of entries in the spreadsheet, some analysis was performed on a dataset provided to the Center by the Chesapeake Stormwater Network (CSN). While the DNR data was used to estimate typical costs, the CSN dataset was used to draw conclusions about specific design features.

In addition to basic descriptive statistics and plots, such as box plots, the analysis used a classical statistical approach, including linear regression, ANOVA analysis, and Tukey Honest Significant Difference test. The analyses were conducted using the basic R statistical program, as well as the “multicomp” package, which included the Tukey analysis. The same statistical methodologies were used for both the DNR and CSN datasets, although some different assumptions were needed for each.

### Summary and Screening of the DNR Dataset

Prior to analysis, the collected data was evaluated for consistency and completeness. All numerical values were checked to ensure consistent units, and any physical specifications that were provided in the project’s description but were not entered by the respondent were added as well. Once data adjustments were complete, the stormwater management projects were sorted according to the completeness of the associated data.

The projects categorized as “most complete” had data for total cost, design cost, construction cost, some/most physical specifications, and most nutrient removal efficiencies. “Somewhat complete” projects had data for total cost, either design or construction cost, some physical specifications, and some nutrient removal efficiencies. While the projects in the “least complete” category were missing the total cost, both the design and construction costs, most physical specifications, and most nutrient removal efficiencies. Table 2 shows the distribution of completeness following this stratification.

| Table 2. Distribution of Projects Following Completeness Categorization | |
|---|---|
| **Completeness** | **Count** |
| Most Complete | 97 |
| Somewhat Complete | 98 |
| Least Complete | 11 |

The practices with the most complete data were then separated by practice type into the following categories: bioretention basins/bioreactors/rain gardens, ponds, swales, and regenerative stormwater conveyance/step pool conveyance systems. This dataset was further refined to include only those projects where:

1. The practice type was provided and was a stormwater BMP with a defined drainage area and pollutant removal efficiency. This eliminated bayscaping, conservation landscaping, tree planting, rainwater harvesting, and other practices from the list.
2. The total cost was provided
3. The data provided allowed for some estimation of the practice WQv.

After removing the BMPs with an invalid practice type and/or without a total cost reported, the number of BMPs was limited to 67 practices. After applying the third screen to these 67 practices, only the remaining 18 reported the WQv. The WQv is a direct measure of the amount of stormwater that can be treated by a BMP, and is used as a common measurement of BMP sizing across all of the BMP types in stormwater design standards for all of the states in the Chesapeake Bay watershed. Consequently, it is an ideal single measurement to compare the unit cost of stormwater BMPs between practice types (e.g., stormwater wetlands versus bioretention practices) and for individual practices within a practice type, such as comparing the unit costs between two individual bioretention practices.

Since the WQv was not directly reported for many of the designs included in this database, a series of assumptions was used to estimate it when data were available. The WQv can be calculated based on the design storm, drainage area and a runoff coefficient based on land use characteristics (see Appendix D for calculations). In this database, the Center estimated the WQv using different assumptions depending on the data available for a particular practice. For example, the design storm was not reported for many practices, and in these cases a default depth of 1" was used to estimate the volume. The flow chart depicted in Figure 1 illustrates the approach. Taken together, the Center estimated the WQv for an additional 28 practices using this approach, for a total of 46 BMPs.

Of the 46 BMPs analyzed, the funding timeframe ranged from fiscal year 2009 to fiscal year 2015, and projects were completed within three years of receiving funding. The Center used the Bureau of Labor Statistics Consumer Price Index Inflation Calculator[2] to estimate inflation rates in order to bring all costs up to the same date, using January of the fiscal year as the initial year and January of 2018. Table 3 provides a summary of the BMPs included in the analysis and Table 4 summarizes the cost information that was provided for these BMPs.

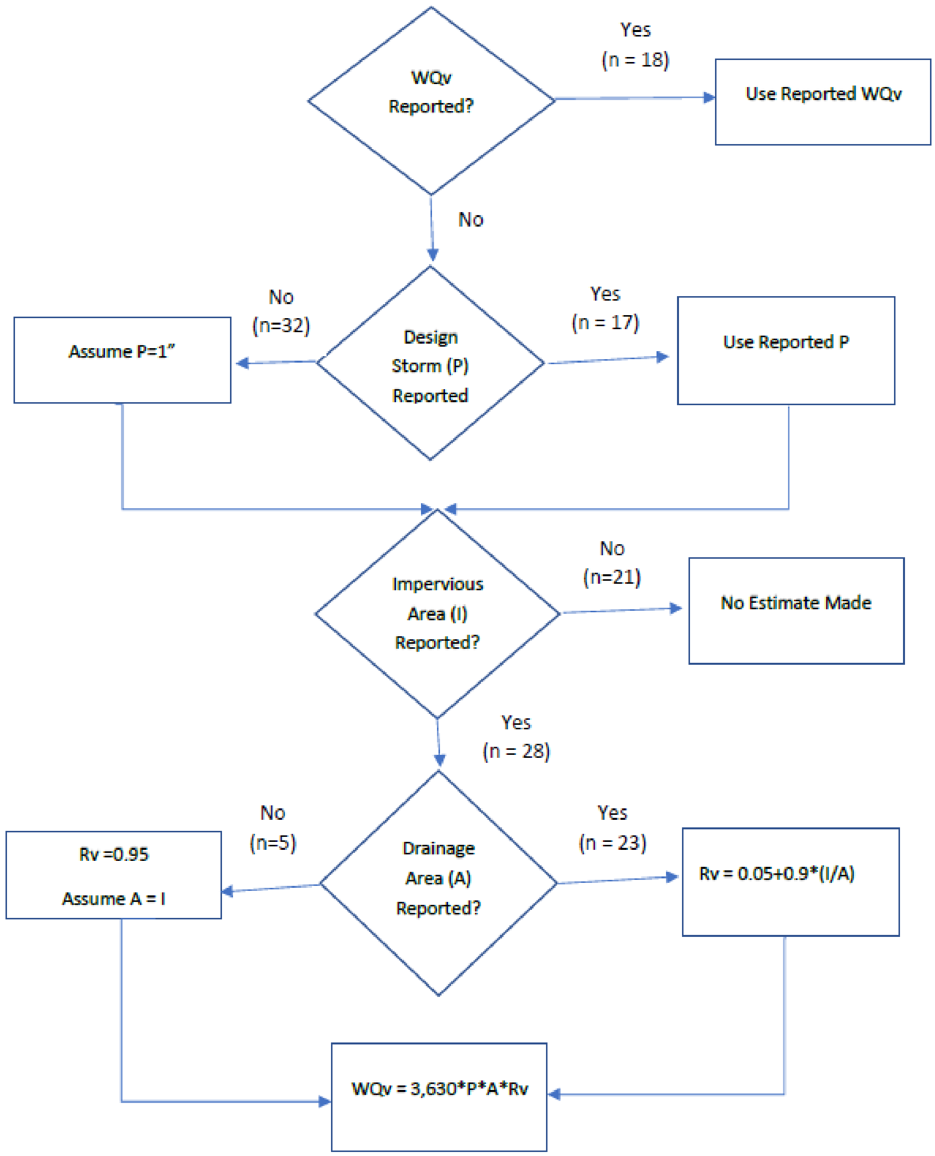


**Figure 1. Decision tree for calculating the WQv of the 46 BMPs included in this analysis**

[2] https://data.bls.gov/cgi-bin/cpicalc.pl

| Table 3. Summary of the 46 BMPs Included in the Statistical Analysis | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Practice Type** | **County or City** | **Partner Type** | **Land Use** | **Land Ownership** | **Design-Build vs. Separate** | **Underdrain Present? (Bioretention Only)** | **Fiscal Year Funded** |
| | | | <u>New Practices</u> | | | | |
| Bioretention | 3 Anne Arundel<br>1Baltimore City<br>2 Frederick<br>7 Howard<br>1 Prince George's<br>12 Talbot<br>1 Washington (Hagerstown) | 16 County<br>10 Non-Profit<br>1 Municipality | 3 Commercial<br>9 Institutional<br>2 Other<br>5 Park<br>6 Residential<br>1 ROW<br>1 N/A | 10 Private<br>17 Public | 11 Design-Build<br>15 Separate<br>1 N/A | 12 No<br>14 Yes | 1 FY09<br>4 FY10<br>3 FY11<br>2 FY13<br>17 FY14 |
| Ponds and Wetlands | 2 Anne Arundel<br>3 Howard<br>1 Talbot | 4 County<br>2 Non-Profit | 1 Commercial<br>3 Residential<br>1 Park<br>1 N/A | 1 Private<br>4 Public<br>1 N/A | 1 Design-Build<br>4 Separate<br>1 N/A | | 1 FY10<br>3 FY13<br>2 FY14 |
| Other Practices | 5 Anne Arundel<br>2 Dorchester<br>1 Washington (Hagerstown) | 3 Municipality<br>5 Non-Profit | 2 Institutional<br>2 Park<br>2 Residential<br>2 ROW | 4 Private<br>4 Public | 4 Design-Build<br>4 Separate | | 3 FY13<br>5 FY14 |
| | | | <u>Modified Practices</u> | | | | |
| 1 Bioretention<br>2 Dry Ponds<br>1 Wet Pond<br>1 Wetland | 4 Howard<br>1 Prince George's | 5 County | 4 Residential<br>1 Other | 5 Public | 4 Separate | | 1 FY10<br>3 FY12<br>1FY 15 |

| Table 4. Summary of Data Provided for the BMPs Included in this Study's Statistical Analysis | | | | |
|---|---|---|---|---|
| **Practice Type** | **Construction Cost** | **Design Cost** | **Permitting Cost** | **Field Investigation** |
| *New Practices* | | | | |
| Bioretention (27) | 20 | 14 | 5 | 6 |
| Ponds and Wetlands (6) | 4 | 4 | 1 | 3 |
| Other Practices (8) | 8 | 6 | 0 | 6 |
| *Modified Practices* | | | | |
| 1 Bioretention<br>2 Dry Ponds<br>1 Wet Pond<br>1 Wetland | 5 | 5 | 4 | 0 |

## Results and Discussion

### Unit Costs Across BMP Types

With the available data, we first created box plots of unit cost ($/cubic foot of WQv) for BMP types (Figure 2) with at least five data points. We combined dry ponds, wet ponds, and wetlands into a single category for this initial summary, and we also created a combined category for practices that were identified as a modification of an existing BMP. Summaries for each BMP type include only new BMPs, and BMP modifications are grouped into a separate category. Based on this initial data summary, it appears that bioretention is on average more expensive on a per unit basis than ponds and wetlands. There are only a few BMPs reported as a modification of an existing BMP, and these include two wet ponds, a wetland, a bioretention, and a dry pond. Since there are only a few of these practices, we did not include them in further analyses.

The cost plots also indicate that the unit cost (in $/cf of WQv) is highly variable for each practice type. This result suggests that simply multiplying a unit cost (in $/cf of WQv) by a practice volume may not provide a very good prediction of the cost. The following sections evaluate other methods for estimating practice costs.

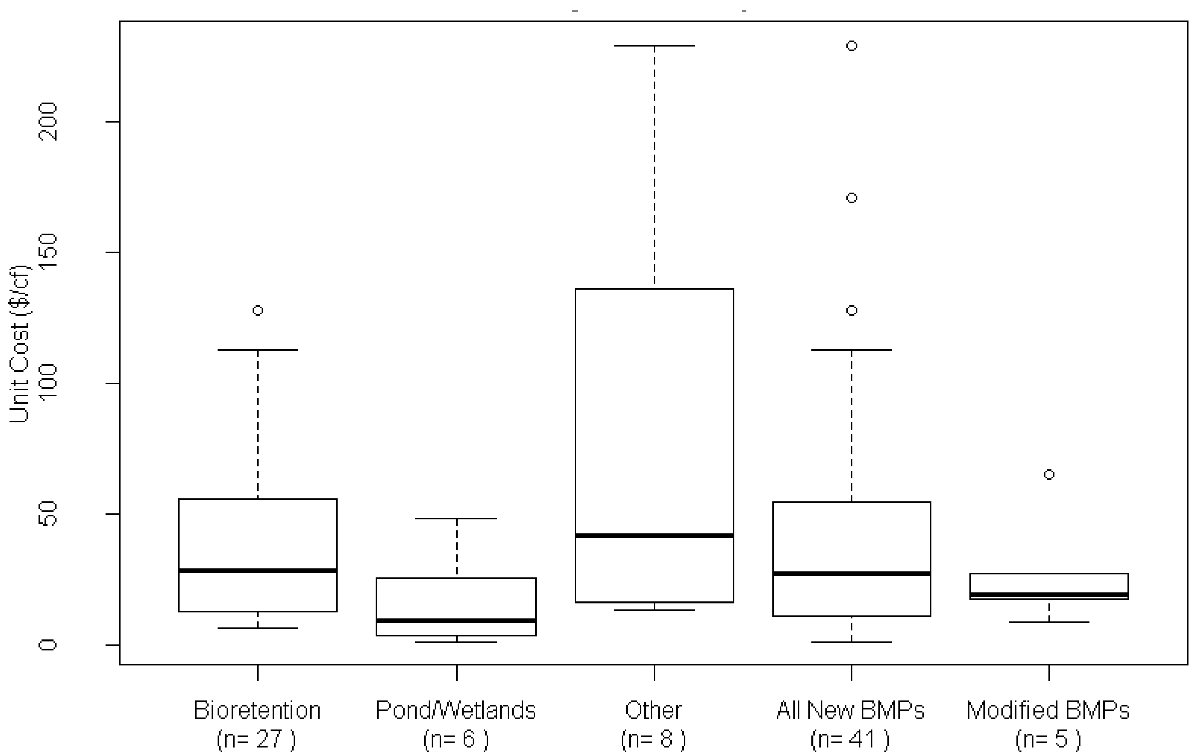


**Figure 2. Unit BMP costs ($/cf of WQv) of retrofits by BMP type**

### Costs vs. Water Quality Volume

We hypothesized that the variability in unit cost can be at least partially explained by the economies of scale, so that the total cost can be more accurately calculated as a regression between WQv and total cost than by a single unit cost. The resulting curves (for all new BMPs, and for bioretention only), are included in Figure 3.

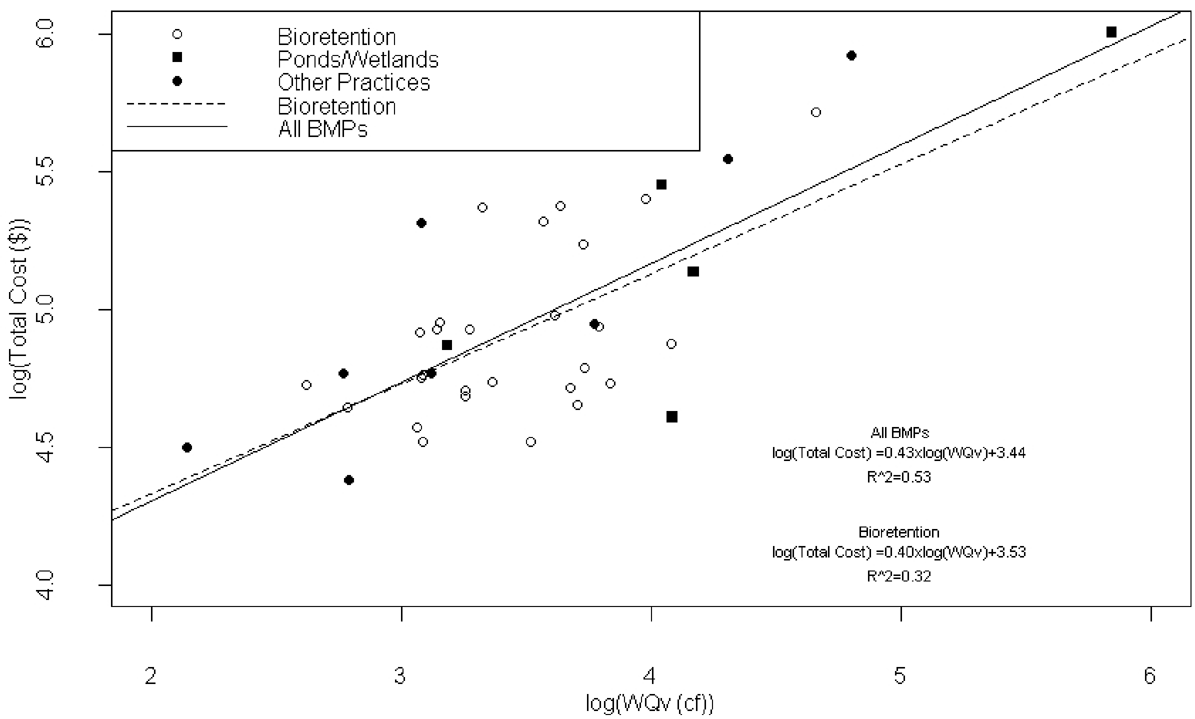


**Figure 3. Relationship between WQv and cost for stormwater retrofits**

Although the model fit appears to be better when all BMPs are considered, we conducted the remaining analyses using bioretention practices alone, since we anticipated that there may be inherent cost differences between different BMPs that are masked by other factors, such as ponds being located preferentially in certain locations or on certain land uses. Although the model fit is statistically significant (p = < 1%), the model accounts for only 32% of the overall variability ($R^2 = 0.32$). Consequently, we conducted an ANOVA analysis to evaluate which variables can explain the overall variability after accounting for the effects of storage.

### Other Predictors of BMP Cost

Since the model fit accounts for only 32% of the overall variability ($R^2 = 0.32$), we conducted an ANOVA analysis to evaluate which other variables can help to explain the overall variability—after accounting for the effects of WQv. This would improve cost estimates based on WQV alone. Since some of the data are fairly sparse, we focused on the following parameters, which are available for most or all of the bioretention practices:

- County where constructed
- Partner type
- Design build vs. separate phases
- Land ownership (public vs. private)
- Land use
- Underdrain (presence or absence)

Of these parameters, only the County where the bioretention practice was constructed and the presence of an underdrain showed the potential to be a statistically significant predictor of BMP cost (Table 5).

**Table 5. ANOVA Analysis Results for Factors Affecting Cost (after accounting for volume treated)**

| Factor | DF[1] | F-Value[2] | p-Value[3] |
|---|---|---|---|
| County | 6 | 8.97 | < 0.01 |
| Partner Type | 2 | 1.28 | 0.30 |
| Design-Build | 1 | 0.46 | 0.50 |
| Land Use | 5 | 0.83 | 0.54 |
| Underdrain | 1 | 5.56 | 0.03 |

*[1] DF: Number of parameters estimated for this variable.*
*[2] F-value: Statistic used to measure the size of differences within a category, relative to the overall variability of the data.*
*[3] p-value: probability that the differences observed would occur if there was really no difference.*

When we evaluated the impacts of both the County and the presence/absence of an underdrain together, we found that the underdrain was not a significant predictor once the County was already known ($p = 0.48$). This result was partially due to the fact that certain counties were more likely to construct practices with an underdrain. Since our data did not have an equal distribution of land uses represented within each County, the effect of County density could not be separated from the other analyzed factors. As Table 6 indicates, certain counties have BMPs with particular characteristics. For example, the practices from Talbot County are typically built without an underdrain, while most of those in Howard County are built with an underdrain. As a result, we were not able to entirely disentangle the presence of an underdrain from the county factor.

| Table 6. Summary of BMP Characteristics by County | | | | | | |
|---|---|---|---|---|---|---|
| **City or County** | **Total** | **Partner Type** | **Land Use** | **Land Ownership** | **Design-Build vs. Separate** | **Underdrain Present?** |
| Anne Arundel | 3 | 3 Non-Profit | 2 Commercial<br>1 Other | 3 Private | 3 Separate | 1 No<br>2 Yes |
| Baltimore City | 1 | 1 Non-Profit | 1 Other | 1 Public | 1 N/A | 1 N/A |
| Frederick | 2 | 2 Non-Profit | 2 Institutional | 2 Private | 2 Design-Build | 2 Yes |
| Howard | 7 | 4 Non-Profit<br>3 County | 4 Institutional<br>2 Park<br>1 Residential | 4 Private<br>3 Public | 4 Design-Build<br>3 Separate | 6 Yes<br>1 No |
| Prince George's | 1 | 1 County | 1 Institutional | 1 Public | 1 Separate | 1 Yes |
| Talbot | 12 | 12 County | 1 Commercial<br>1 Institutional<br>3 Park<br>5 Residential<br>1 ROW<br>1 N/A | 1 Private<br>11 Public | 5 Design-Build<br>7 separate | 2 Yes<br>10 No |
| Hagerstown (Washington) | 1 | 1 Municipality | 1 Institutional | 1 Public | 1 Separate | 1 Yes |

After adding the County to the regression equation, it appears that, on average, it is more expensive to construct BMPs in counties with higher population densities. In order to compare these specific differences, we used the Tukey Honest Significant Difference (HSD) technique to compare means between each county, after taking the volume differences into account. In Table 7, positive values indicate that the higher density county—listed in descending order from top to bottom and left to right—results in higher costs, and a p-value of $< 0.10$ indicates that the finding is statistically significant at 10% significance. These results suggest that:

- Howard County is significantly more expensive than Anne Arundel, Frederick, and Talbot Counties;
- Prince George's County is significantly more expensive than Talbot County; and,
- Washington County is significantly more expensive than Talbot County.

| Table 7. Tukey Honest Significant Difference Between Counties[1,2,3]. (Cells highlighted in green indicate a significant relationship ($p \leq 0.10$)) | | | | | | |
|---|---|---|---|---|---|---|
| | **Howard** | **Prince George's** | **Anne Arundel** | **Washington[4]** | **Frederick** | **Talbot** |
| **Baltimore City** | -0.10 p=0.99 | -0.25 p=0.90 | 0.30 p=0.62 | -0.18 p=0.78 | 0.27 p=0.78 | 0.31 p=0.45 |
| **Howard** | | -0.14 p=0.97 | **0.40 P=0.05** | -0.07 p=1.00 | **0.37 p=0.08** | **0.42 p=0.00** |
| **Prince George's** | | | **0.54 p=0.07** | 0.07 p=1.00 | 0.51 p=0.14 | **0.56 p=0.03** |
| **Anne Arundel** | | | | -0.48 p=0.15 | -0.03 p=1.00 | 0.02 p=1.00 |
| **Washington** | | | | | 0.44 P=0.26 | **0.49 p=0.07** |
| **Frederick** | | | | | | 0.05 (p=1.00) |

*[1] Counties listed from top to bottom and left to right in descending density.*
*[2] Positive values indicate that the higher density county is more expensive.*
*[3] Values in bold are statistically significant at the 10% significance level.*
*[4] Washington is placed after Anne Arundel based on the population density of the entire county. However, knowing that the individual practice was constructed in Hagerstown, it could arguably have been placed as the second densest county after Baltimore City.*

All of the statistically significant differences are consistent with the overall indication that BMPs are more expensive to build in more highly urbanized counties. While there are some negative values among higher density counties (e.g., between Baltimore City and a few other counties), these p-values are extremely high, indicating no substantive statistical difference. It is also important to note that there was only one practice in Baltimore City, which explains why no statistical difference was found between the City and any other jurisdiction. Additionally, Washington County appears to be slightly more expensive than one would anticipate (i.e., a few negative but non-significant differences with higher density counties), but there was also only one practice built in this county, located within the City of Hagerstown.

Next, we used the population density to divide counties into high-density and low-density categories and used this factor in the cost-prediction equation. We placed Baltimore City, Howard County, Prince George's County, and Washington County into the high-density category, and the remaining jurisdictions were placed into the low-density category. The resulting equation has an $R^2$ value of 0.78 and a p-value of almost 0 (Figure 4). Categorizing the counties based on density allows the cost equation to be applied to counties outside the few for which data were available in this study. On average, it is more expensive to construct BMPs in Maryland counties with higher population densities. Typically, total cost was about 2.7 times as much in more urbanized counties.

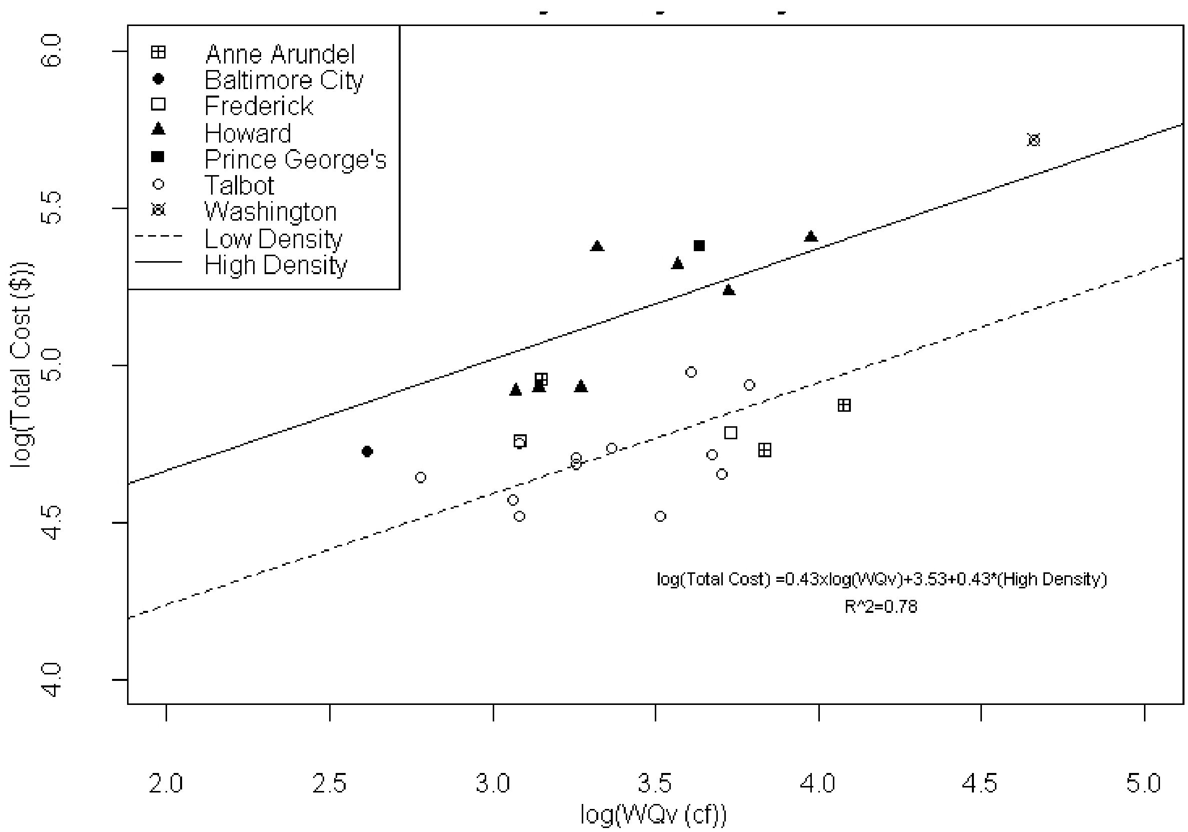


**Figure 4. Regression between bioretention WQv and total cost for counties with low and high population density**

### Cost Breakdown

Although not every practice reported the design, construction, permitting, and field-investigation costs, we estimated these costs as a fraction of the total reported cost based on the data from practices where these costs were reported. Figure 5 suggests that construction is by far the largest portion of the cost—with a median value of approximately 85%. Design was also significant, with a median of 11% of the costs. In these practices, permitting and field investigation were very small with median permitting cost less than 1% of the total cost and median field investigation between 2% and 3% of the total cost.

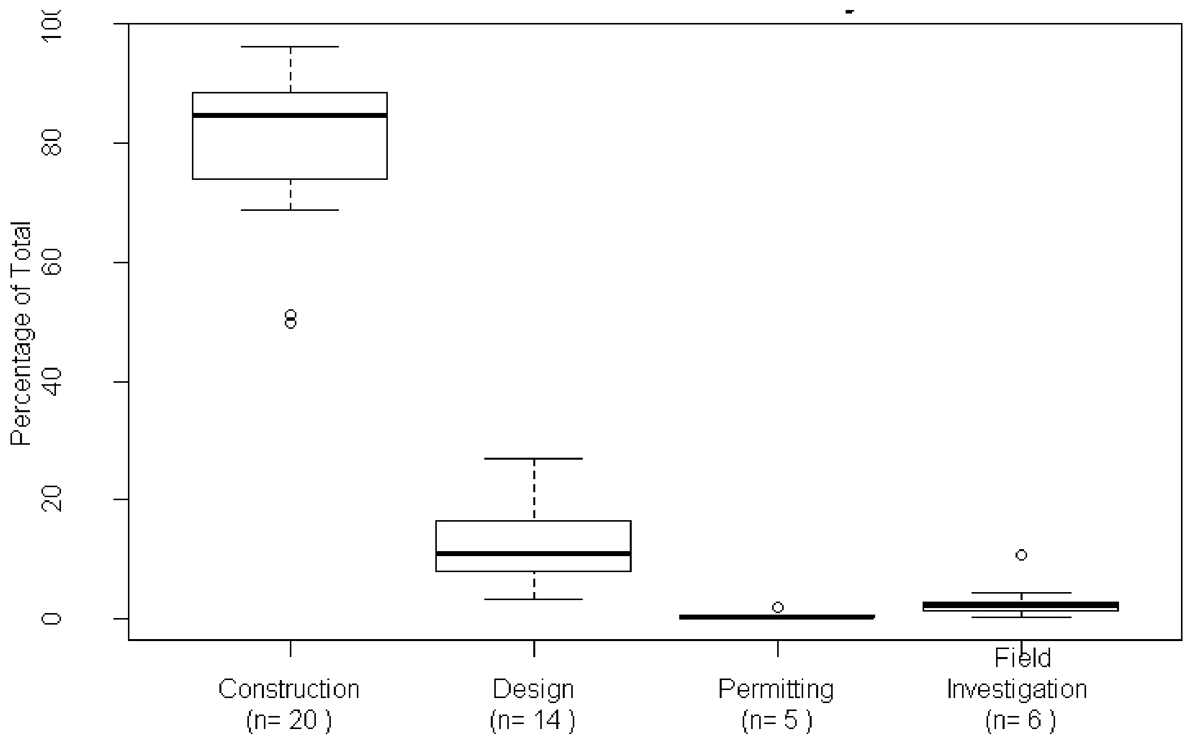


**Figure 5. Construction, design, permitting and field investigation as a percentage of total cost for bioretention**

## Supporting Analysis: Chesapeake Stormwater Network Bioretention Data

Although the data obtained as a part of this study were useful for developing planning level costs estimates for bioretention practices, there were some data gaps that prevented many of the study questions to be answered. As a brief supporting analysis, the Center reviewed some of the data collected on BMP costs by the Chesapeake Stormwater Network in 2012. The data were collected through a national survey and include projects from Colorado, Washington, D.C., Maryland, Minnesota, Pennsylvania and Virginia. The survey asked users to break down construction costs by particular elements, and to identify specific design elements.

### Modifications to the CSN Data Set

The CSN data were modified in two ways:

1) The data were restricted to retrofits only, eliminating new construction and redevelopment projects.
2) Projects identified as "Multiple BMPs" were eliminated from the analysis.
3) Costs were adjusted for inflation using the Bureau of Labor Statistics CPI Inflation Calculator to adjust from the Fiscal Year funded reported in the database to 2018 dollars.

The resulting data set included 22 bioretention practices. All these practices included construction cost estimates, and complete data regarding construction challenges and design elements. Only a few had a complete cost breakdown by design element.

## Methods and Questions Investigated

The CSN data included several specific construction elements, such as presence of a constructed outfall, use of an infiltration test, and use of specialized inlet structures. It was not possible to isolate the effects of each of these design elements because they tended to overlap. For example, most practices with an underdrain also had a constructed outlet structure. Consequently, we use the presence of an underdrain as a surrogate for practices with complex "piping."

Similarly, we used the presence of utilities as a surrogate for site constraints. There was a "space constraints" question as well, and sites with utility constraints tended to also have space constraints. Other specific site challenges were rare, and we consequently could not evaluate their effects. For example, only one site had access issues, and none had problems with bedrock.

We used this data set to investigate the following questions:

1) Is the presence of an underdrain a useful indicator of construction cost?
2) Does the presence of utilities increase the construction cost?

To evaluate these questions, we first used an ANOVA analysis to determine if these effects were significant, after accounting for the design volume. The results initially suggested that both land use and the presence of an underdrain are indicators that the practice will be more expensive (Table 8). However, when we account for both factors simultaneously, we find that, after we already account for the presence of an underdrain, the presence of utilities is no longer a useful predictor. It is not possible to separate the presence of utilities from the use of an underdrain since every site with utilities also used an underdrain in the design.

**Table 8. ANOVA Analysis Results for Factors Affecting Cost (after accounting for volume treated)**

| Factor | DF[1] | F-Value[2] | p-Value[3] |
|---|---|---|---|
| *Considering Factors Individually* | | | |
| Utilities | 1 | 5.8 | 0.03 |
| Underdrain | 1 | 21.5 | <0.01 |
| *Considering Both Factors Simultaneously* | | | |
| Utilities | 1 | 0.04 | 0.85 |
| Underdrain | 1 | 20.4 | <0.01 |

*[1] DF: Number of parameters estimated for this variable*
*[2] F-value: Statistic used to measure the size of differences within a category, relative to the overall variability of the data.*
*[3] p-value: probability that the differences observed would occur if there was really no difference.*

The results suggest that presence of an underdrain is a good indicator of BMP cost. Although the underdrain itself is not a large part of the overall practice cost, it is generally a good indicator of a more complex, and typically more urbanized, construction setting. Presence of an underdrain also represented a meaningful cost increase. The construction cost of practices with an underdrain were, on average, 4.4 times as expensive as those without an underdrain.

## Supplemental Interviews

Since there was insufficient quantitative data to further explore statistical relationships, supplemental interviews with grantees were conducted to collect qualitative information to help further enhance the study findings and fill in some blanks. The interview questions that were provided to the respondents are available in Appendix B.

Ten DNR partners were contacted to request interview responses. Responses were obtained from four of the nine DNR partners with BMPs included in this study (Table 9). Respondents A, C, and D provided written responses, while Respondent B opted for a phone interview. The only other interaction of note was one DNR partner—a managerial employee of a large non-profit organization—who was approached for an interview declined because he/she stated that all of the organization's BMP cost estimates are carried out by contractors. The results of the interviews are summarized below.

**Table 9. Interview Respondent Background Information**

| Respondent ID | Partner Type | State | Municipality Characteristics |
|---|---|---|---|
| Respondent A | County | Maryland | Low-Density |
| Respondent B | County | Maryland | Low-Density |
| Respondent C | County | Maryland | High-Density |
| Respondent D | Non-profit | Maryland | N/A |

### Approaches to Cost Estimation

The respondents provided two main approaches to cost estimation: measurement-unit-based estimation and estimation based on comparisons to previous project work. For estimates made prior to putting the contract out to bid, Respondents A, C, and D solely use previous projects of the same magnitude. However, Respondent B suggests doing no form of cost estimation prior to putting contract out to bid for two main reasons: because of an inclination to "[take estimates] to legislative bodies very cautiously" and because of the “disparity between anticipated costs and how the bids actually come in.”

For cost estimation at the project planning level, all respondents use the costs of previous projects in similar environments as a gauge; however, Respondents A and D supplement those estimates with unit-based estimation. For bioretention projects, Respondent D uses a metric of price per square foot of surface area, while Respondent A uses a value of $30,000 per impervious acre treated for estimations for all types of practices. Respondent B is hesitant to use unit-based estimates, however, since there is so much site-to-site variance in his/her experience. Before putting a project out to bid, Respondent B encourages completing a detailed field assessment (soil testing, utility location mapping, etc.) in order to demonstrate “fiduciary due diligence” and to land on the most accurate estimate possible. Respondent B does acknowledge the major downside of this method, which is higher up-front project costs; however, he/she justifies this estimation method by noting the potential “to avoid unexpected issues later on during construction that would end up costing even more.”

### Influence of Project Type on Cost Estimates

Cost estimation is also influenced by the type of project in question. Respondents A, B, C, and D find bioretention/rain garden/bioswale projects the easiest to estimate costs for. Respondent A stated that the hardest practices to estimate the cost of are “new structural facilities and facilities in karst locations.” Respondent B reports difficulty with estimates for ditch retrofits. In contrast to the other respondents, Respondent C stated that larger ponds and wet ponds are the most difficult to approximate costs for because “they have the greatest chance of having large dredging costs or being re-categorized as higher hazard dams with greater design/construction requirements.”

### Variability in Estimated Versus Actual Costs

When it comes to project cost variability, the respondents were split. Respondent D reported extreme variability in his/her examples of a previous bioretention project, whose estimated cost was $70,000 and actual costs were $19,000. Both Respondents B and C stated that their estimates are typically within reason compared to their actual costs. Both also acknowledged that there is, of course, some variability between estimated and actual costs, but the variances tend to balance each other out. When summarizing his/her experience, Respondent B concluded that “more than 65% of the time, actual implementation costs are pretty consistent with the planning-level cost estimates that were used to secure federal/state funding.” Contrary to Respondent D, Respondent A stated that his/her estimated costs are almost always very close to the actual cost of implementation.

## Difficulties with Cost Estimation Specificity

All four respondents mentioned their own unique difficulties when it comes to producing accurate, specific cost estimates. As a result, their respective organizations do not tend to break their costs down into anything more detailed than design/engineering, permitting, and construction. Interestingly, all four respondents explained different roadblocks primarily relating to construction cost estimation. Respondent A finds construction costs to be the most difficult to estimate because of unexpected site conditions like groundwater, rock, and utilities, while Respondent B struggles with construction cost estimation because of market fluctuations in material costs. Both Respondents A and B find design and permitting costs to be relatively predictable; however, Respondent A mentioned that those costs "may increase if additional untreated drainage area can be brought into the facility or if a State/Federal permit review requires a design change." Respondent D finds County grading and site development plan redlining costs to be the most difficult to approximate; he/she also mentions that, while permitting is generally predictable, when permits are required, overall costs can be increased anywhere from 20%–30%. Respondent C finds earthwork (dredging for ponds) and whether or not MD Dam Safety is involved to be the most variable and influential on overall project costs.

## Willingness to Provide Specific Cost Estimates

While none of the respondents had any issue providing their cost estimates from a transparency standpoint, the logistical difficulties of such a request were abundant. Respondent A was the most hesitant to provide data since "most of [his/her organization's] proposals are lump sum bids, so no unit price breakdown is currently required." Respondent C said he/she was certainly willing; however, it would "likely be time consuming," and "almost every project [his/her organization does] has a site-specific quirk that influences the cost, so 'typical' costs for review/funding agencies could be problematic to assess." Respondent B was also willing, but his/her willingness "would be contingent on state/federal funding agencies having a consistent template and providing training, so they know how to get information to potential granters effectively." Respondent B added that "the 'one-size fits all' approach to BMP cost estimation is ineffective, as it would inevitably lead to necessary grant modifications after it has already been awarded." Similarly, Respondent D explained how "specificity in grants greatly limits flexibility in implementation since asking for permission for changes is a tremendous amount of paperwork and time spent with DNR accountants." Respondent D concluded his/her thoughts by saying, "specificity can get you too deep into accountability."

### Challenges with Cost Estimation and Lessons Learned

The two main challenges faced by the respondents are funding constraints and dealing with the public/local residents. Respondents B and D both feel that funding is their biggest challenge when it comes to BMP implementation. Respondents C and D emphasized the commonness of problems with local residents/adjacent property owners. Respondent C explained that "after construction, any changes in the neighborhood are often deemed a direct result of our retrofit." Unlike the other respondents, Respondent A struggles the most with lack of flexibility from state/federal permitting authorities, which has added years to some of their projects.

### Suggestions for Improved Cost Estimates

In terms of addressing their concerns, Respondents A, B, and D provided their insight on data that would assist them in estimating costs. Respondent A requested soil borings, wetland delineations, and historic data on similar projects to those constructed in his/her County. Respondent B elaborated on how helpful a repository of stormwater retrofit or watershed management plans (that contain 10% design) from other jurisdictions in Maryland would be. Respondent D requested specific data on the seasonal fluctuations in material costs. He/she explained this need with an anecdote about how—two and a half months prior to construction—a construction worker at a quarry said, "when the building season start[s], the cost of rock would go up 30%." As a result of this information, Respondent D's organization "stockpiled and bought a bunch before the building season," which they would not have known to do without the quarry worker's market insights. In addition to requesting an Expert Panel on BMP cost estimation, Respondent B presented a powerful suggestion:

> *"We need to be working at a basin level. It makes no sense to be working at a county level. It doesn't matter how much you do, if the county upstream isn't doing their part, the importance of the work I do downstream is minimized. DNR and MDE should have regional planners available at the basin level to assist with grant writing, implementation, and reporting (similar to MD DOT and the Department of Planning). DNR has done a tremendous job working with their parties, but I still think there's a tremendous amount of dialogue that needs to take place with local governments. Let us help you help us."*

## Findings and Recommendations

### Findings

The most apparent finding of this study was that the data collected were not sufficient to answer all of the research questions. In particular, there were not enough BMPs for which complete responses were provided to be able to draw conclusions from the analysis on how specific factors, such as design features or permit required, affected BMP costs. In addition, most of the data collected were for bioretention practices, which limited the ability to compare costs and cost-effectiveness across BMP types.

There are several reasons the dataset on which analysis could reasonably be performed was so limited. Through our data collection efforts, we learned that many organizations working on retrofit implementation do not collect the type of BMP information and cost breakdown needed to answer the research questions. In some cases, the BMPs were constructed five or more years ago, so digging up the data was considered too time-consuming and/or difficult. These factors, in addition to the usual challenges with getting responses to a survey (i.e., typical response rates for a targeted survey are in the 25%–40% range), affected the volume of data acquired for analysis.

Some specific examples of the discrepancy between the requested data and what grantees were able to provide include:

- Some organizations do not do any cost estimating themselves but simply rely on a lump sum cost estimate from contractors bidding for the work. They often do not require any more detailed cost breakdown from the contractor. They are therefore unable to break out costs any further than a total cost.
- The water quality volume, which is one of the most important factors needed for estimating cost and pollutant removal, was not reported by many of the responding grantees. Grant applications often ask for impervious acre treated and/or loads reduced for proposed and final metrics. However, the applications do not ask for the water quality volume although this is an important factor in BMP effectiveness and shown to be a predictor of BMP cost.
- Few respondents were able to provide a breakdown of BMP costs further than design costs, construction costs, and total cost. This information was either not tracked or was tracked in a format that did not lend itself to easily determining a more detailed cost breakdown. For example, if the BMP design was done in-house, the cost was often not accounted for in the total.

Key findings from the analysis include:

- On average, bioretention is more expensive on a per unit basis ($/cf of water quality volume) than ponds and wetlands. However, the unit cost is highly variable, and economies of scale play an important part of this effect. Larger bioretention practices are also more cost-effective than smaller practices.

- Water quality volume is the single most reliable predictor of practice cost. When we included all the BMPs in the database (including bioretention), we could account for 53% of the variability in the cost using this variable alone. When only considering bioretention practices, water quality volume alone accounted for 32% of the variability in cost.
- Based on this data set, as well as a supplemental review of data collected by the CSN, presence of an underdrain is a good predictor of BMP cost. This effect is not due to the cost of underdrain piping itself, but rather due to the underdrain as a predictor of the complexity of the practice itself. In the DNR data set, the setting (as indicated by the county/jurisdiction where construction occurred) was a better indicator of practice cost.
- On average, it is more expensive to construct BMPs in Maryland counties with higher population densities. Typically, total cost was about 2.7 times as much in more urbanized counties. This result is consistent with data from the CSN suggested that having an underdrain (another potential indicator of a complex design) increased the construction cost by 4.4 times.
- For bioretention practices, design costs (including field investigation and permitting) were around 15% of the total cost, while construction was around 85% of the total cost (based on median values). The design costs were typically lower (as a percentage) than those estimated by King and Hagan (2011). It is possible that the reported costs evaluated in this study did not include a full representation of the costs related to design, as the DNR Trust Fund prioritizes the most cost-effective projects to support with funding, meaning that many of the funded retrofits had another (and possibly unreported) source of funding for design, or did the design in-house which is more difficult to track as an expense.
- We were unable to develop cost curves for all of the types of BMPs funded and could not isolate specific influences on BMP cost other than the setting where the practice was built, based on county density. This was largely due to the relatively small size of the dataset.

The supplementary interviews provided additional findings on the methods and challenges of estimating stormwater retrofit costs, and data needs to help improve these estimates:

- Some entities rely solely on contractor estimates for retrofit costs and do not have the capacity to develop cost estimates in-house

- Others use unit costs (e.g., $/cf of treatment) to initially make estimates but these unit costs are not useful to account for the variability from site to site
- Still others base their estimates on historic costs from projects of a similar size/type; yet, there is a need for more of this data to help improve the cost-estimating process
- The most difficult costs to predict include permitting, earthworks and those related to unexpected site conditions. In particular, whether or not Maryland DNR will classify a pond as a high hazard dam is an unknown that can greatly increase project costs
- The BMP type that was easiest to predict costs for in this study was bioretention/rain gardens. This may be because it is the BMP for which the most data is available
- The BMP types that were most difficult to predict costs for in this study included ponds (due to the permitting issues mentioned above), ditch retrofits and structural facilities located in karst areas
- The types of data that would be helpful to improve retrofit cost estimates include: information on seasonal fluctuations in material costs, historic cost data on similar projects from similar locations, and costs for soil borings and wetland delineations
- The biggest challenges with implementing retrofits include: getting sufficient funding, understanding the site conditions (in enough detail to come up with a reliable cost estimate but without spending too much money up front on a project that may not pan out), unexpected site issues (e.g., “surprise” utilities or poor soil conditions), permitting (which can be so onerous that projects are intentionally kept below disturbance thresholds that may trigger grading permits), the fact that every project is different, and dealing with the public, who may have concerns about the proposed project (e.g., mosquitos in bioretention after a rain).

## Recommendations

The original intent of this study was to increase our understanding of stormwater retrofit costs to help entities implementing these practices improve the reliability of their cost estimates. While the analysis of the limited data collected did result in some useful findings for BMP cost estimation, it is evident that some basic changes are needed in how BMP information is accounted for and reported so that a consistent database of constructed retrofit costs can be developed for future use. Knowing the true cost of these BMPs will help funders to direct grants toward the most cost-effective practices and ensure that funding thresholds are appropriate given the expected cost. In addition, understanding the major factors affecting cost is an important step toward devising ways to reduce those costs.

Recommendations for funding agencies are provided below in two key areas: 1) collection of BMP and cost data from grantees at project completion, and 2) provision of guidance and tools to assist communities with estimating both planning-level and detailed costs for stormwater retrofits. Some of these recommendations were informed by the data analysis results, while others were developed by the Center in response to the lack of consistent guidance on cost estimating for stormwater retrofits in Maryland.

### Grantee Reporting Requirements

We recommend that key funders of implementation in the Chesapeake Bay—including CBT, DNR, and NFWF—consider evaluating their grantee reporting systems/requirements and discuss what changes can better facilitate gathering consistent useful data for retrofit cost estimation. Appendix C provides a list of recommended elements to be collected as part of the final grant report. In particular, the addition of the WQv as a required reporting element would facilitate future comparison of costs across constructed BMPs, and would also facilitate better estimates of cost-effectiveness, impervious cover treated and pollutant removal. Appendix D describes how to calculate the water quality volume for a given retrofit.

As many organizations are shifting towards use of the FieldDoc application for tracking, an update to the FieldDoc requirements for completed projects could be a simple way to influence tracking across a large number of grant-funded retrofits. On the other hand, we recognize that many grantees are not highly technical and may have difficulty using tools such as FieldDoc or applying the equation in Appendix D. There is a need in the Chesapeake Bay Watershed for a simple tool or tools that these lower-tech applicants and grantees can use estimate potential pollutant reductions, water quality volume and other commonly-required information. Another recommendation for the funding agencies is to develop and offer a set of simple tools that meet this need as part of their funding programs' application resources.

The intent of these recommendations is that over time a more consistent dataset of costs and characteristics of constructed retrofits will become available to help answer the research questions identified in this study. In order to realize efficiencies and adaptively manage future years based on past year data, funding agencies should summarize and analyze their data on constructed retrofits on an annual basis to see what can be learned about how retrofit costs vary by BMP type, location, or other characteristics. The research community can play a role in compiling this data across funding agencies and other implementers and evaluate this more robust dataset.

### Guidance for Estimating Costs

We recommend that funding agencies also provide guidance and resources on retrofit cost estimation as part of their funding programs' application resources. The information provided below can be used to help develop this guidance.

Ideally, cost estimating can be done in stages that include a planning-level or ballpark estimate prior to detailed site investigation (e.g., topographic survey) and design, and a more refined cost estimate that accounts for the site conditions, permit requirements and specific BMP dimensions. Planning-level costs are often used to help prioritize a list of projects in a plan, as well as to develop capital improvement project budgets, grant proposals, or bid packages to design and construct the projects. Planning-level estimates can be based on unit costs (e.g., $/cf of treatment), comparison to historic projects of a similar size/type, or some combination of the two.

In the absence of reliable data from previous, similar projects, entities can use the unit costs in Table 10 to develop planning-level costs for retrofit construction. The costs in Table 10 are from King and Hagan (2011) and have been converted from dollars per impervious acre treated to dollars per cubic foot of treatment (cost per impervious acre are provided for reference). These costs include design, permitting and construction but do not include purchase of land or any long-term costs such as operations and maintenance. These values should be adjusted based on the complexity of the proposed project as well as on historical data where available.

| Table 10. Unit Costs for Developing Planning-Level Estimates for Stormwater Retrofits | | | | |
|---|---|---|---|---|
| **Retrofit Type** | **Construction Costs ($/cf)[1]** | **Design (as % of Construction)[2]** | **Total Cost ($/cf)** | **Total Cost ($/impervious acre)** |
| Wet Ponds and Wetlands[3] | $5.38 – $12.37 | 30% – 50% | $6.99 – $18.56 | $24,115 – $63,998 |
| Infiltration Practices[4] | $12.10 – $12.68 | 40% | $16.95 – $17.76 | $58,450 – $61,250 |
| Sand Filter[5] | $10.15 – $11.60 | 40% | $14.21 – $16.24 | $49,000 – $56,000 |
| Bioretention [6,7] | $10.87 – $38.05 | 25% – 40% | $13.59 – $53.28 | $46,875 – $183,750 |
| Vegetated Open Channels | $5.80 | 20% | $6.96 | $24,000 |
| Bioswale | $8.70 | 40% | $12.18 | $42,000 |
| Permeable Pavement[8] | $63.15 – $88.41 | 10% | $69.46 – $97.25 | $239,580 – $445,412 |
| Dry Pond Conversion to Wet Pond or Wetland[9] | $3.59 | 50% | $5.39 | $18,573 |

*[1] Modified from King and Hagan (2011), by converting from $/impervious acre treated to $/cf by assuming 1 inch of runoff treated per impervious acre.*
*[2] Source: King and Hagan (2011)*
*[3] Low end cost is for suburban settings while the high end is for more urban settings*
*[4] Low end cost is for practices without sand while the high end is for practices with sand*
*[5] Low end cost is for above ground practices while the high end is for below ground practices*
*[6] Low end cost is for suburban settings while the high end is for more urban settings*
*[7]The equations following this table may provide a more accurate planning level cost estimate.[8] Low end cost is for practices without sand while the high end is for practices with sand*
*[9] Cost for conversion of dry pond to wet pond or wetland derived from (CWP 2013)*

For bioretention practices, the cost equation derived from the analysis of bioretention cost data in this study can be used as an alternative to the use of unit costs in Table 10. The resulting curves are as follows:

***For a High Density (Urbanized) setting:***

$$C = 9{,}120 \times V^{0.43}$$

***For a Low Density (non-Urbanized) setting:***

$$C = 3{,}388 \times V^{0.43}$$

As Figure 6 indicates, the estimated costs would lie within the range of unit costs from King and Hagan for practices larger than about 8,000 cf. This is equivalent to a practice sized to treat about 2.3 acres of impervious cover. The King and Hagan (2011) costs may overestimate the cost of highly urbanized practices above this size, and overestimate them above this size

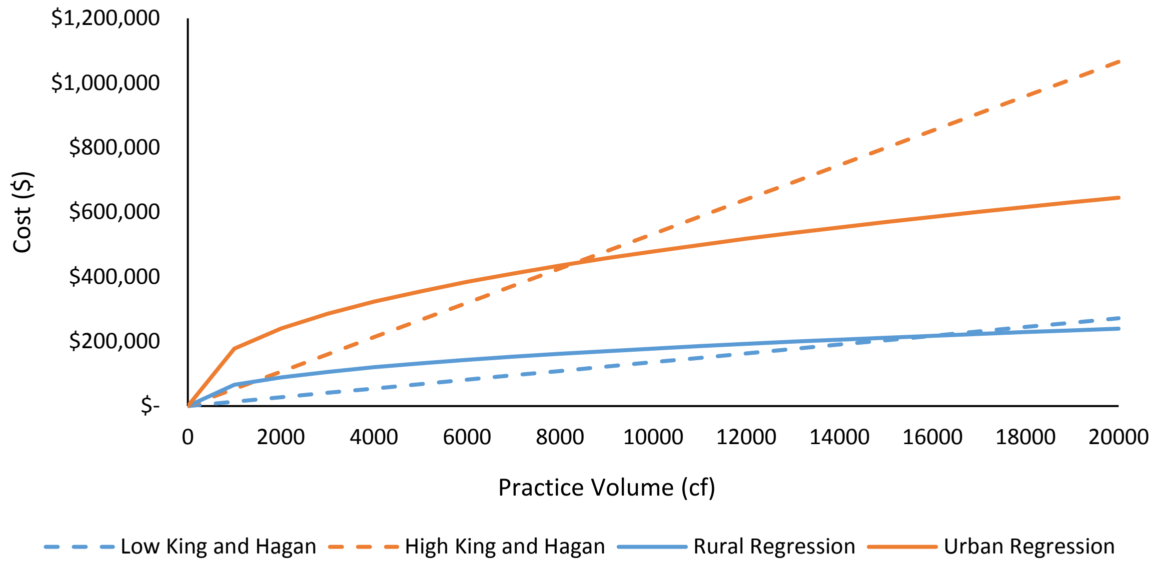


**Figure 6. Comparison of regressions to King and Hagan (2011) cost estimates for bioretention**

As an individual project progresses beyond the concept stage, a more refined cost estimate can be made by the designer of the cost to construct the BMP. Box 1 lists many of the typical considerations for costs at this stage.

**Box 1. Cost Considerations for Stormwater Retrofit Construction**

Engineering and Permits

- Site investigation (topographic survey and/or geotechnical analysis)
- Completion of design and construction plans
- Printing of plan sheets
- Permitting fees and associated labor (completing permit applications, attending pre-application meetings)
- Construction inspections – time and travel costs
- Development of as-builts, if required

Construction Materials and Labor

- Mobilization ($/lump sum)
- Construction fence ($/lf)
- Tree protection fence ($/lf)
- Tree removal (ea)
- Stabilized construction entrance (ea)
- Silt Fence ($/lf)
- Excavation ($/cy)
- Hauling ($/cy)
- Drainage pipe ($/lf)
- Infrastructure modifications (ea)
- Stone($/cy)
- Sand/filter media ($/cy)
- Mulch ($/cy)
- Topsoil ($/cy)
- Filter fabric ($/sy)
- Plants (ea or $/sy)
- Permanent stabilization ($/sf)
- Contingency (10-20% of total)

Unit costs for the elements in Box 1 can vary, but it is recommended that retrofit project managers compile this information (in addition to the data in Appendix C) into a repository they can draw from for future projects. This data compilation will allow them to determine the cost to construct projects of similar type/size/condition, as well as to evaluate this dataset to determine if certain project types cost more than others.

## References


Brown, W. and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium by the Center for Watershed Protection. Silver Spring, MD.

Center for Watershed Protection. 2013. *Cost Effectiveness Study of Urban Stormwater BMPs in the James River Basin*. Prepare by the Center for Watershed Protection for the James River Association. Ellicott City, MD.

Jones, C., Branosky, E., Selman, M., and M. Perez. 2010. *How Nutrient Trading Could Help Restore the Chesapeake Bay*. World Resources Institute. Washington, DC.

King, D., and P. Hagen. 2011. *Costs of Stormwater Management Practices in Maryland Counties*. Prepared for Maryland Department of the Environment by the University of Maryland Center for Environmental Services. Technical Report Series No. TS-626-11 of the University of Maryland Center for Environmental Science.

Schueler, T., Hirschman, D., Novotney, M., and J. Zielinski. 2007. *Urban Stormwater Retrofit Practices Version 1.0*. Center for Watershed Protection. Ellicott City, MD.

U.S. Environmental Protection Agency Office of Water. 1999. *Preliminary Data Summary of Urban Storm Water Best Management Practices*. Washington, D.C.

## Appendix A. Grantee Instructions for Data Entry

**Green Infrastructure Retrofit Cost Study**

The Center for Watershed Protection is leading an effort to update cost data on green infrastructure (GI) retrofits by compiling and analyzing data from the Maryland Department of Natural Resources' database of more than 500 constructed GI retrofits. The goal is to learn more about their design and construction costs; what factors affect cost variability; which are most cost-effective for nutrient and sediment removal; and identify common lessons learned and challenges. The product will be a white paper that Maryland communities can use to inform planning and budgeting, direct their limited resources towards the most cost-effective GI practices, and ultimately make these projects more successful.

For each constructed retrofit, the Center is requesting the following information from grantees. A spreadsheet is provided with yellow highlighted fields for the needed information in the "Database 7.18.2017" tab. Please complete as much of the sheet as possible for your projects. Note that each BMP should have its own line, so add additional lines as needed.

<u>Costs of Labor and Construction</u>

- **Total cost:** enter the total cost for field investigation, design, permitting, construction and construction oversight of the project. Include DNR grant funds as well as all other leveraged or matching funds.
- **Field investigation cost:** enter the cost of survey and geotechnical analysis.
- **Design cost:** enter the cost of field evaluation of site (do NOT include costs associated with discovery of retrofit sites), preliminary design, and final design.
- **Permitting cost:** enter the staff time and fees associated with permitting.
- **Construction cost:** enter the supplies and labor associated with BMP construction.
- **Construction oversight cost:** enter the engineering costs associated with construction oversight and as-builts.
- **Field investigation labor:** indicate whether field investigation (survey, geotechnical analysis) was done in-house or contracted out

- **Design labor:** indicate whether project design was done in-house or contracted out
- **Permitting labor:** indicate whether permitting was handled in-house or contracted out
- **Construction labor:** indicate whether construction was done in-house or contracted out
- **Construction oversight labor:** indicate whether construction oversight was done in-house or contracted out

<u>Other Factors that May Influence Cost</u>

- **Type of retrofit:** indicate whether the practice is a "new" retrofit (e.g., installation of a BMP on developed land where none previously existed) or modification of existing BMP (e.g., conversion of dry pond to wet pond).
- **Design-build versus separate phases?:** was this a design-build project or were the design and construction completed by separate firms in two phases?
- **Land owner:** select public or private land ownership
- **Project type:** indicate whether the project was part of a larger project (e.g., a parking lot reconstruction) or "stand-alone" retrofit
- **ESC permit required?:** did the project exceed the disturbance threshold for an erosion and sediment control permit? (select yes or no)
- **Other Permits Required:** list other permits needed, such as wetlands permits, if known.
- **Primary land use:** select the primary land use for the site on which the practice is located: residential, commercial, industrial, institutional, ROW, park, or other.
- **Utility conflicts?:** Select yes if utility conflicts were a design issue, and list conflicts in notes.

<u>BMP Design Information</u>

- **Overall BMP Type:** This is an overall category selected from a drop-down menu: 1) Bioretention and bioretention variants, 2) Other micro-scale practices, 3) Other Environmental Site Design practices, 4) Traditional BMPs (except bioretention), and 5) Proprietary or Other practices

- **BMP Group:** list the BMP type (Based on MDE Manual Categories http://www.mde.state.md.us/programs/water/stormwatermanagementprogram/documents/Urban%20BMP%20Database%20for%20Phase%20II%20MS4s%202016.pdf), from a drop-down menu
- **Design Variant:** Select the specific design variant (if applicable, from the MDE Manual), from a drop-down menu
- **Practice Name or Description:** This field is designed for Proprietary or Other practices. It can also be used if the Overall BMP Type, BMP Group or Design Variant are unknown. Enter the practice type in this field.
- **Underdrain?:** select yes or no to indicate whether an underdrain was used
- **Drainage area (acres):** enter the size of the area draining to the practice, in acres
- **Impervious cover in drainage area (acres):** enter the area of impervious cover present in the drainage area, in acres
- **Practice Surface Area (sf):** Enter the area *at the practice surface*. For bioretention, this will be the area of the filter medium.
- **Total Area Consumed by the Practice (sf):** This field is not absolutely necessary, but if available should include the surface area at the extents of the practice.
- **BMP Water Quality Storage Volume (cf):** enter the water quality volume treated by the practice (in cubic feet). The "BMP Design Volume" Worksheet will assist with estimating this volume if it is unknown.
- **Water Quality Design Storm Treated (inches):** enter the amount of rainfall (in inches) treated by the practice, if plans or documents identify.
- **Additional Storage for Quantity Controls (cf):** For practices with supplemental storage for floods or channel protection, please enter this volume here.
- **Pretreatment Methods:** Select the general approach to providing pretreatment from a drop-down list.
- **Overflow:** describe how overflow is handled from this practice, from a drop-down menu.
- **Unique design features:** list any unique design features or enhancements to the basic design of the practice

Practice Benefits

- **Annual TN reduction (lbs/yr):** enter the annual nitrogen load reduction (pounds per year) provided by the practice, if known.
- **Annual TP reduction (lbs/yr):** enter the annual phosphorus load reduction (pounds per year) provided by the practice, if known.
- **Annual TSS reduction (lbs/yr):** enter the annual sediment load reduction (pounds per year) provided by the practice, if known.
- **Other goals met:** list any other requirements or goals in addition to stormwater (e.g., energy reduction for green roofs, tree or landscaping targets) met by the project

Notes

- **Notes:** use this space to note any additional information of importance

## Appendix B. Supplemental Interview Questions

1. Do you feel that you have sufficient data available to estimate the costs to design and construct stormwater BMP retrofits? If not, what type(s) of data would be helpful?
2. Do you find that general BMP costs (in $/IA or $/cf captured, for example) are useful first estimates for planning purposes, or do you use a different method to budget for your projects? If you use general estimates, what is the source of the data?
3. In general, have you found that actual constructed stormwater BMP costs are higher, lower or about the same as what your organization originally estimates?
4. When you estimate BMP costs, which specific costs are difficult to predict? (examples include design, construction, materials, permits, permitting, or some specific design features)
5. Which BMP types are the easiest to estimate costs for? Which are the most difficult?
6. What specific data would help you estimate BMP costs most effectively?
7. We have found that funding agencies are not requiring grantees to provide BMP costs and other data in the format and level of detail necessary to be able to better understand the total costs and factors that affect BMP costs. As a grant recipient, would you be willing to provide more detailed cost and design data to help develop a better database for estimating BMP costs, and are there certain data that would be difficult to provide?
8. What have been your biggest challenges or lessons learned with implementing stormwater BMP retrofits?

## Appendix C. Recommended Data to Collect at Grant Closing

**Grant Closing Checklist**

| General | | Land Use |
|---|---|---|
| Partner name: | ______ | ☐ Commercial<br>☐ Residential<br>☐ Institutional<br>☐ Industrial<br>☐ Park<br>☐ Other (please describe): ______<br><br>Description:<br>______<br>______ |
| Grant ID: | ______ | |
| Type of practice: | ______ | |
| Site name: | ______ | |
| City: | ______ | |
| State: | ______ | |
| Year installed: | ______ | |
| **Practice Sizing** | | **Setting** |
| Drainage area (ac): | ______ | ☐ Urban<br>☐ Suburban<br>☐ Rural |
| Impervious cover in DA (ac): | ______ | |
| Design storm (in): | ______ | |
| **Practice Dimensions/Description** | | **Other Design Considerations** |
| Surface area (sf): | ______ | ☐ Modification of an existing BMP<br>☐ New practice<br><br>☐ Stand-alone project<br>☐ Part of a larger project |
| Ponding depth (ft): | ______ | |
| Media depth (ft): | ______ | |
| Stone depth (ft): | ______ | |
| Treatment volume (cf): | ______ | |
| **Special Design Elements** | | **Design Challenges** |
| ☐ Underdrain<br>☐ Overflow structure<br>☐ Infiltration testing:<br>☐ Specialized conveyance structures<br>☐ Media enhancements<br>☐ Mechanized or "smart" features<br>☐ Additional site preparation (e.g., impervious removal)<br>☐ Other (please describe): ______<br><br>Additional details:<br>______<br>______<br>______ | | ☐ Access<br>☐ Easements<br>☐ Utilities<br>☐ High water table<br>☐ Space constraints<br>☐ Bedrock<br>☐ Special permits needed<br>☐ Property use conflicts<br>☐ Other (please describe): ______<br>Additional details:<br>______<br>______<br>______ |

| Cost Summary | |
|---|---|
| Design: | ___ |
| Construction (materials): | ___ |
| Construction (labor): | ___ |
| Construction (oversight/management): | ___ |
| Permitting (fees & inspections): | ___ |
| Other costs: | ___ |
| Total cost: | ___ |

Please describe any unexpected conditions that increased or decreased the estimated cost of this practice.

## Appendix D. Equation for Calculating Water Quality Volume

$$WQv = 3{,}630 \times P \times Rv \times A$$

Where:

$WQ_v$ = Water Quality Treatment Volume (cf)

P = Design Storm (in.)

Rv = Runoff Coefficient

A = Drainage Area (acres)

3,630 = Conversion factor from ac-in to cf

$$Rv = \frac{\sum A_i Rv_i}{A}$$

Where:

$A_i$ = Area of Land Cover/Soil i

$Rv_i$ = Runoff Coefficient for Land Cover/Soil I (see table/ alternative method below))

| Land Cover/Soil | Rv |
|---|---|
| Impervious Cover | 0.95 |
| Grass – HSG A | 0.15 |
| Grass – HSG B | 0.20 |
| Grass – HSG C | 0.22 |
| Grass – HSG D | 0.25 |
| Source: Adapted from: Battiata, J., K. Collins, D. Hirschman and G. Hoffmann. "The Runoff Reduction Method". Journal of Contemporary Water Research and Education, 146(1). https://doi.org/10.1111/j.1936-704X.2010.00388.x | |

The runoff coefficient can also be estimated based solely on the impervious cover, using the equation:

Rv = 0.05+0.009*I, where
I = Impervious Cover Percentage