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Environmental Security Technology Certification Program (ESTCP)

Stormwater Management and Optimization Toolbox

Heidi R. Howard, Chad Helmle, Raina Dwivedi, and Daniel R. Gambill

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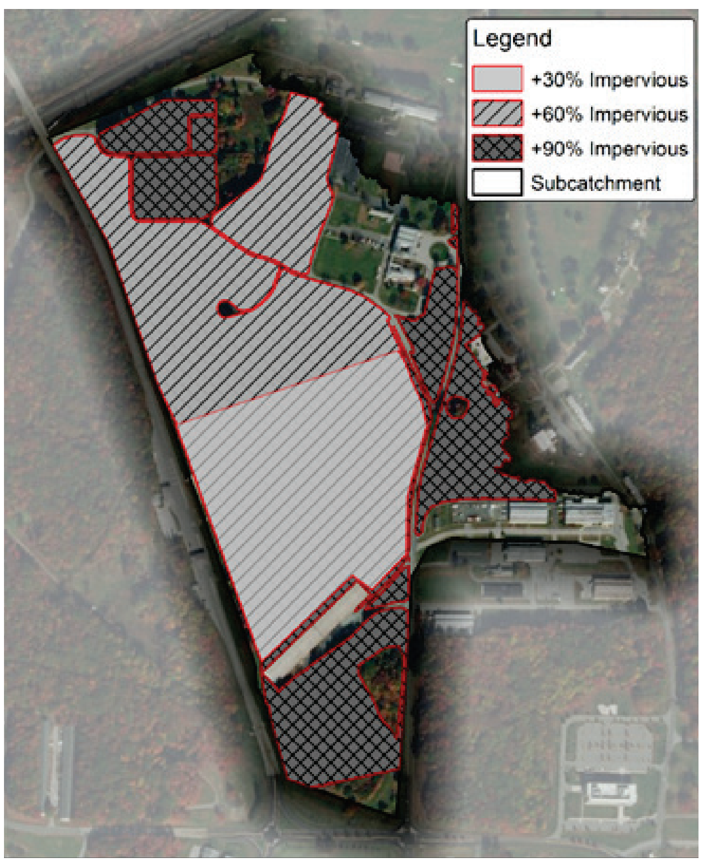

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Construction Engineering Research Laboratory

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Abstract

As stormwater regulations for hydrologic and water quality control become increasingly stringent, Department of Defense (DoD) facilities are faced with the daunting task of complying with multiple laws and regulations. This often requires facilities to plan, design, and implement structural best management practices (BMPs) to capture, filter, and/or infiltrate runoff—requirements that can be complicated, contradictory, and difficult to plan. This project demonstrated the Stormwater Management Optimization Toolbox (SMOT), a spreadsheet-based tool that effectively analyzes and plans for compliance to the Energy Independence and Security Act (EISA) of 2007 pre-hydrologic conditions through BMP implementation, resulting in potential cost savings by reducing BMP sizes while simultaneously achieving compliance with multiple objectives. SMOT identifies the most cost-effective modeling method based on an installation's local conditions (soils, rainfall patterns, drainage network, and regulatory requirements). The work first demonstrated that the Model Selection Tool (MST) recommendation accurately results in the minimum BMP cost for 45 facilities of widely varying climatic and regional conditions, and then demonstrated SMOT at two facilities.

Contents

Figures and Tables

Figures

Tables

Preface

Funding for this demonstration was provided by the Strategic Environmental Research and Development Program (SERDP) under Environmental Restoration (ER) Project RC-201305, “Resource Conservation and Resiliency Projects.”

This work was conducted by the Ecological Processes Branch, Installations Division, Construction Engineering Research Laboratory, Engineer Research and Development Center (ERDC-CERL). Dr. Chris Rewerts was Chief of the Ecological Processes Branch, and Michelle J. Hanson was Chief pf the Installations Division. The associated Technical Director was Alan Anderson. The Acting Deputy Director of ERDC-CERL was Michelle J. Hanson and the Acting Director was Dr. Kumar Topudurti.

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Executive Summary

Objectives of the demonstration

As stormwater regulations for hydrologic and water quality control become increasingly stringent, Department of Defense (DoD) facilities are faced with the complex and difficult task of simultaneously complying with multiple laws and regulations, such as the Energy Independence and Security Act (EISA) of 2007 and the Clean Water Act Total Maximum Daily Loads (TMDLs), and with the need to secure Municipal Separate Storm Sewer Systems (MS4) permits. This often requires facilities to plan, design, and implement structural best management practices (BMPs) to capture, filter, and/or infiltrate stormwater runoff. These requirements can be complicated, contradictory, and difficult to plan. As a result, many DoD facilities overbuild or oversize these BMPs to ensure compliance.

This project demonstrated the Stormwater Management Optimization Toolbox (SMOT), a spreadsheet-based tool specifically designed to help DoD facilities achieve compliance with regulatory stormwater requirements at minimal cost. The demonstration took place in two phases: (1) a demonstration that recommendations of the Model Selection Tool (MST) accurately results in the minimum BMP cost for 45 facilities located in regions with widely varying climatic and regional conditions, and (2) a demonstration of SMOT at two facilities to showcase the capabilities of the model platforms, illustrate the ease of implementation, and ultimately validate the model selection element.

Technology description

SMOT is spreadsheet-based tool comprised of the MST, Scaled Model Platforms, and BMP Sizing Tool/Master Plan. SMOT has the ability to effectively analyze and plan for BMP implementation, resulting in potential cost savings by reducing BMP sizes while simultaneously achieving compliance with multiple objectives. SMOT identifies the most cost-effective modeling method based on an installation's local conditions (soils, rainfall patterns, drainage network, and regulatory requirements).

SMOT uses national datasets to gather watershed characteristics information, and then processes the information through the MST, which makes recommendations of the modeling method to use. SMOT recommends one modeling method out of three possible alternatives: a simple design storm approach (e.g., the 95th percentile rainfall treatment), a simple continuous simulation approach, or a continuous simulation approach that is coupled with optimization.

After the MST identifies the general modeling method, specific watershed models identified in the Scaled Modeling Platforms are used to carry out the modeling analysis. Modeling results from the recommended platform are then fed into the BMP Sizing Tool to guide the implementation process. The BMP Sizing Tool within SMOT estimates the required BMP sizes for the new development for the subwatershed in which the new development occurs, the area of the new development, and the desirable type of BMP to be implemented.

On the basis of the modeling results, the BMP Sizing Tool interpolates the BMP volume and area required (expressed in the depth of runoff to be captured/infiltrated) as development occurs in the subwatershed of interest. If development is planned for a subwatershed with constraints identified, SMOT helps select a substitute location (subwatershed) within the larger watershed with higher potential infiltration than the proposed development subwatershed. The BMP Sizing Tool allows a design engineer to select the type of BMP, to size the BMP, and to customize layer depths of a BMP. Finally, SMOT provides a basic report of the selected BMP including typical cross-section of the BMP and major dimensions.

SMOT is able to assist with various stormwater management efforts, from analysis method selection (MST), to actual modeling analysis (Scaled Modeling Platforms), to final BMP implementation (BMP Sizing Tool or BMP Master Plan) across DoD facilities. The Toolbox is expected to help DoD facilities achieve substantial cost savings during the process of complying with stormwater regulations.

Demonstration results

In Phase 1, the project team effectively demonstrated the MST at 45 installations located in regions with varying climatic and regional conditions. MST was able to match runoff predictions by the Stormwater Management Model (SWMM) with a strong correlation of R2>0.98 and a low relative absolute error for total runoff volume (RAE<10%). When MST was assessed against the System for Urban Stormwater Treatment Analysis and

Integration (SUSTAIN) overflow, MST was able to mimic outputs with a high level of correlation ($R2>0.99$) and a close approximation in total runoff volume (RAE<10%). It was concluded that the MST could serve as a reasonable alternative to the SWMM for runoff volume, and to the SUSTAIN model for BMP simulations.

In Phase 2, the project team successfully demonstrated SMOT at two facilities, Aberdeen Proving Grounds (APG) and Naval Air Station (NAS) Key West. The team conducted a full-scale demonstration using detailed modeling approaches for continuous simulation coupled with or without optimization (SWMM or SUSTAIN). These modeling approaches were applied at a single subwatershed at each installation and then at the subcatchment basin for NAS Key West. The selected subwatersheds within each installation had development potential, so modeling was conducted for 30%, 60%, and 90% impervious surfaces. BMP size results from the full-scale modeling efforts were compared against each of the modeling approaches, and finally against the original MST recommendations and SMOT outputs. For APG, the BMP size results from the full-scale modeling efforts resulted in outputs within 10% of each other and greater than the continuous approach by 10% for the Design Storm approach. These results confirm that optimization does not yield significant savings for APG and that the recommendations from MST and detailed modeling efforts are consistent at APG.

Full-scale modeling at NAS Key West identified that continuous simulation done both with and without optimization resulted in BMP sizes that were 10% smaller in size than the continuous simulation. When models were applied at the subcatchment scale, the resulting BMP sizes again confirmed that the continuous simulation with optimization was the correct modeling approach for NAS Key West. These results validated the MST outputs and confirmed that the MST is appropriate and applicable at all scales

The use of SMOT has the potential to help DoD identify appropriate modeling approaches and significantly reduce BMP implementation costs. SMOT helps eliminate the guesswork of selecting a model method; it can reduce modeling costs by predicting when sophisticated modeling can be avoided; it can help reduce BMP sizes and costs through optimization when it is cost-effective; and finally, it can streamline the compliance and design processes by providing simplified guidance in the form of a BMP Sizing Tool or Master Plan.

1 Introduction

The stormwater community has come to recognize that the choice of modeling method used to comply with stormwater regulations impacts the compliance analysis. As those modeling methods change, stormwater practitioners have increasingly seen great differences in Best Management Practice (BMP) sizing requirements (Reese and Parker 2014). The Stormwater Management Optimization Toolbox (SMOT) integrates a firm understanding of the factors that contribute to these BMP size differences while synthesizing that knowledge into practical tools. SMOT sets the standard as a user-friendly tool that can readily assist installations achieve regulatory compliance with substantial cost savings. SMOT consists of four main components:

1. The compilation of input data to the toolbox
2. The MST for the recommendation of a cost-effective modeling approach
3. A detailed modeling of platforms
4. The BMP Sizing Tool for implementation and tracking. When SMOT is applied at an installation, the user first prepares baseline watershed characteristics data that will be input into the toolbox. The input data are then analyzed by the MST component for recommendations of modeling approaches. When detailed modeling is completed following the approach recommended by MST, specific sizing requirements for BMPs are identified for the installation to comply with applicable regulations. Subsequently, the BMP Sizing Tool component of SMOT is activated, guiding base engineers to plan, assess, implement, track, and report development and BMP implementation activities. Cost-effective BMP sizing requirements from the detailed modeling analysis are incorporated throughout the tool. Compliance application packages that summarize project details are also prepared through the BMP Sizing Tool component.

A crucial component of SMOT, MST was enhanced in the Phase I development of the toolbox through numerous demonstration studies of MST across various climatic and watershed conditions. The goal of the Phase I demonstration was to enable the tool to identify cost-effective modeling approaches for complying with stormwater regulations at various installations with reliable accuracy. The Phase I demonstration report confirmed the usability and applicability of MST across a wide range of installations using readily available input characteristic data.

Phase II demonstration of SMOT was intended to execute the full suite of capabilities at two installations to demonstrate comprehensive stormwater regulation compliance assistance. At each installation, site-specific data were gathered and processed to characterize the watershed and compliance needs. Then, the modeling approach recommendations made by the MST component of SMOT were verified against detailed, installation-scale modeling analysis results. BMP sizing analysis results following detailed modeling were then incorporated into BMP implementation elements of SMOT for both installations. BMP implementation elements then served as the guide for site selection, design, and construction of BMPs at the two installations. These example applications of SMOT now serve as the user's guide for similar applications in other installations.

1.1 Background

The process of urban development leads to deterioration of both hydrologic and water quality runoff conditions. In response to growing concerns about adverse environmental impacts resulting from urban stormwater runoff, regulatory agencies continue to adopt stringent requirements to limit or mitigate downstream hydrologic and water quality impacts. Examples of these requirements include section 438 of the EISA, Total Maximum Daily Load (TMDL) allocations, hydromodification management, and other municipal permits. Many of these regulations establish numerical limits on runoff quantity and quality from a property. To comply with these regulations, military installations must carry out modeling analyses to identify appropriate sizes of BMPs or low impact development (LID) structures for stormwater control, and then construct BMPs accordingly to achieve compliance. This comprehensive process requires close collaboration between modeling analysis and construction activities, especially when BMPs are implemented through different phases at a DoD facility.

Depending on applicable regulations at a DoD facility, established modeling tools are available to carry out the required hydrologic and/or water quality analyses. For example, the U.S. Environmental Protection Agency (USEPA) technical guidance for complying with EISA section 438 regulations specifies two methods for modeling analysis: (1) retain the 95th percentile storm on site or (2) demonstrate (via continuous simulation analysis) no net change in hydrology from the predevelopment condition. While a spreadsheet-based calculation is sufficient for following the first analysis method, hydrologic and water quality models (e.g., Stormwater Management Model [SWMM], Hydrological Simulation Program – Fortran [HSPF], Storage, Treatment, Overflow, Runoff Model [STORM]) are required for continuous simulation. When a facility is subject to TMDL regulations, a watershed model with water quality representations is necessary for carrying out the analysis to demonstrate progress towards addressing the applicable TMDLs. When site conditions (i.e., heterogeneous soils) warrant a spatial optimization analysis, significant cost savings can be realized through the use of sophisticated modeling tools, such as the System for Urban Stormwater Treatment Analysis and Integration (SUSTAIN) or BMP Decision Support System (BMPDSS), which are capable of identifying cost-effective BMP or LID implementation alternatives. Selection of the appropriate modeling tools depends on knowledge of watershed conditions, understanding of regulatory requirements, and the level of expertise available.

Previous studies have demonstrated that the choice of modeling tools can substantially influence BMP sizes. In a pilot study conducted at three Upper Charles River communities in Massachusetts, BMPs that were sized following the uniform design storm approach were found to be about three times the size of those following the continuous simulation coupled with optimization approach (Tetra Tech 2009). In two EISA section 438 compliance studies conducted at Barksdale and Minot Air Force Bases (AFBs) (Tetra Tech 2011a, 2011b), the spreadsheet-based design storm approach (Option 1) was compared side-by-side with the continuous simulation approach (Option 2) coupled with optimization through SUSTAIN. The results indicated that at Barksdale, the SUSTAIN model (Option 2) was able to identify BMP implementation alternatives that reduce the required BMP size by up to 70% (or $18M) in BMP construction costs as compared to Option 1, whereas the two options result in similar total BMP sizes at Minot. When the upfront costs for SUSTAIN model development at both sites are considered, the SUSTAIN model is obviously the better modeling choice for Barksdale AFB, and the spreadsheet-based calculation for Option 1 is the better modeling choice for Minot AFB.

A more recent study (Tetra Tech 2013a) built on the Barksdale and Minot experiences by comprehensively investigating how watershed conditions (e.g., soils, rainfall, and drainage network) at the Air Force Civil Engineer Center

(AFCEC) might impact the required BMP sizes following the two EISA compliance options. The investigation also analyzed the threshold above which the optimization techniques are expected to result in significant cost savings. These efforts were consolidated into a draft version of an MST that could guide a design engineer to choose the most cost-effective modeling tool at an Air Force Base. Depending on specific site conditions, MST recommends one modeling method out of three possible alternatives: (1) a simple design storm approach (e.g., the 95th percentile rainfall treatment), (2) a simple continuous simulation approach, or (3) a continuous simulation approach that is coupled with optimization. Initial tests showed that the draft MST was able to choose the most cost-effective modeling tool at 12 locations across the country for over 90% of the time (Tetra Tech 2013a). More recent studies by Reese and Parker (2014) further confirm that a change in modeling methods could result in drastically different BMP sizes.

The Phase I demonstration of MST investigated the relationship between climate, rainfall, soils, geography, modeling approach, and the eventual BMP sizing for regulation compliance. MST was used on a diverse range of site conditions at 45 sites across the country, and the algorithm for recommending the most cost-effective modeling approach at an installation was further enhanced. The Phase II demonstration built on MST enhancements and completed installation-scale case studies to demonstrate the complete regulatory compliance support provided by SMOT. The demonstration includes all steps that an installation must complete to fully use SMOT, from data compilation to the final compliance applications. For the purposes of serving as examples to future SMOT applications, two installations (APG and NAS Key West) that require different modeling approaches were selected as case studies. The July 2015 memorandum (Subject: "Stormwater Management and Optimization Toolbox Site Selection Memorandum/ Table 1 Performance Objectives Phase 2") provides additional information.

1.2 Objective of the demonstration

The objective of Phase II is to demonstrate the comprehensive compliance support provided by SMOT through full-scale modeling applications at two installations. Detailed modeling analyses (design storm, continuous simulation-only, and continuous simulation coupled with optimization) were completed at APG and NAS Key West, with the resulting BMP sizing results compared against the MST component's recommendations. The comparison verified that MST is capable of choosing the most cost-effective modeling method for satisfying BMP requirements within a watershed or smaller drainage area. Following the detailed modeling and MST demonstrations, the BMP Sizing Tool component of SMOT was also demonstrated for each installation, illustrating the seamless transition from cost-effective BMP sizing to practical BMP implementation, tracking, and compliance application.

1.3 Regulatory drivers

This section contains an overview of EISA section 438, USEPA technical guidance for federal projects under EISA section 438 (USEPA 2009a), DoD guidance on compliance with EISA, and the technical details for complying with EISA regulations as well as other local regulations that might be applicable to military installations.

1.3.1 EISA section 438 and compliance strategies

Congress enacted EISA in December 2007. EISA section 438 establishes strict stormwater runoff requirements for federal development and redevelopment projects. The legislation reads as follows:

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

Section 438 is intended to address the inadequacies of current approaches for managing stormwater and to promote practices that maintain or restore predevelopment site hydrology. Although Congress did not prescribe specific strategies to comply with section 438, it can be inferred that one of the goals of the act is to promote the use of sustainable stormwater management approaches, designs, and practices that better protect receiving water quality and better address volume control (USEPA 2009b). LID is the preferred approach that can be used to meet the criteria of EISA section 438.

To assist federal agencies, USEPA developed its *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act* (USEPA 2009b). This document is intended solely as technical guidance for federal facilities. It is not a regulation and does not impose any legally binding requirements. It is important to note that, for DoD facilities, the DoD policy memorandum takes precedence over USEPA's technical guidance document. USEPA's technical guidance document describes two options for demonstrating compliance with EISA section 438 requirements, each of which is intended to achieve the outcome of maintaining or restoring predevelopment hydrology.

For Option 1, USEPA's 95th percentile methodology is used to determine the design storm. The design storm event is based on the 95th percentile of 24-hour rainfall depth. Appendix A to this report, "EPA Guidance for Estimating the 95th Percentile Rainfall," includes this procedure. The design storm is used to calculate post-development runoff volumes to size LID BMPs to retain on site the runoff from all rainfall events less than or equal to the 95th percentile rainfall event. LID BMPs are encouraged throughout the site design to ensure control and water quality objectives. In USEPA's technical guidance, compliance with EISA regulations through Option 1 was demonstrated with nine case studies, most of which use a direct determination approach to estimate LID sizes (USEPA 2009a). Note that, although this method is intended to maintain or restore predevelopment hydrology, previous studies have demonstrated that it may grossly overcompensate or undercompensate for hydrologic changes resulting from development depending on local conditions (Tetra Tech 2011a, 2011b, 2013a, 2013b).

Option 2 can be used to determine predevelopment hydrology through a site-specific performance design objective. The methods for calculating, modeling, and sizing stormwater runoff are based on continuous simulation concepts. Specific modeling software and consistent hydrological assessment tools are to be used and appropriately documented. If the designer elects to use Option 2, the designer would then identify the predevelopment condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to predevelopment conditions. The post-construction rate, volume, duration, and temperature of runoff should not exceed the predevelopment rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible. These goals should be accomplished through the use of infiltration, evapotranspiration, and/or rainwater harvesting and use.

Although EISA section 438 is focused on the site-level practices, flexibility does exist to use nearby areas or areas directly adjacent to the facility to manage the runoff through evapotranspiration, infiltration, or harvest and use. Under justifiable circumstances, it might also be appropriate to evapotranspirate, infiltrate, or harvest and use an equivalent or greater amount of runoff off-site as long as the runoff is discharged or used in the same receiving subwatershed or watershed (USEPA 2009b).

1.3.2 DoD policy for EISA compliance

In January 2010, DoD released a memorandum that directs facilities to implement EISA section 438 using LID techniques in accordance with the methodology illustrated in that document (OUSD 2010). The following paragraphs provide an overview of the DoD's interpretation of USEPA's technical guidance document, including a clarification of how predevelopment hydrology and maximum extent technically feasible are defined according to DoD.

EISA section 438 requirements are applicable to all DoD construction projects that have a footprint greater than 5,000 gross square feet, or that expand the footprint of existing facilities by more than 5,000 gross square feet. According to DoD, the project footprint is defined as all horizontal hard surfaces and disturbed areas associated with the project development, including building areas and pavements (such as roads, parking, and sidewalks). Those requirements do not apply to internal renovations, maintenance, or resurfacing of existing pavements (DoD 2010).

The overall design objective for each project is to maintain predevelopment hydrology and prevent any net increase in stormwater runoff. DoD defines predevelopment hydrology as the pre-project hydrologic conditions of temperature, rate, volume, and duration of stormwater flow from the project site. The analysis of the predevelopment hydrology must include site-specific factors (such as soil type, ground cover, and ground slope) and use modeling or other recognized tools to establish the design objective for the water volume to be managed from the project site (DoD 2010). The term predevelopment hydrology is not specifically defined in USEPA's technical guidance document; however, it is worth noting that predevelopment hydrology can be defined as the hydrological conditions of a site before any land-disturbing activities occur. The DoD definition takes precedence over any other definitions of predevelopment hydrology.

The net result is that EISA section 438 requirements are triggered *only* by new development greater than existing impervious area footprints.

Section 438 also requires the project site design to achieve the design objective to the METF. According to DoD, METF criterion requires full employment of accepted and reasonable stormwater retention and reuse technologies (e.g., bioretention areas, permeable pavements, cisterns/recycling, and green roofs), subject to site and applicable regulatory constraints (e.g., site size, soil types, vegetation, demand for recycled water, existing structural limitations, state or local prohibitions on water collection). Before finalizing the design for a redevelopment project, DoD components must also consider whether natural hydrological conditions of the property can be restored, to the extent practical (DoD 2010). All site-specific technical constraints that limit the full attainment of the design objective must be documented. If the design objective cannot be met within the project footprint, LID measures can be applied at nearby locations on DoD property (e.g., downstream from the project) within the limits of available resources. Such an interpretation of USEPA's document allows DoD engineers to evaluate compliance with EISA at the DoD facility property boundary, rather than at the project site boundary. That makes it possible to use a holistic, installation-wide strategy to comply with regulations at the AFBs (Krishnan et al. 2011). Furthermore, USEPA's technical guidance document states that the project sponsor "shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property." This clause has been interpreted by DoD to mean that the land surrounding the project site is available to implement the appropriate BMPs where optimal. Although the performance requirements of EISA section 438 apply only to the project footprint, the flexibility exists to use the entire federal property in implementing the stormwater strategies for the project.

In addition to the guidance described above, two Unified Facilities Criteria (UFC) documents provide technical instruction for designing BMPs and conducting hydrologic and hydraulic analyses (UFC 3-210-10, *Low Impact Development* [NAVFAC 2015], and UFC 3-230-01 *Surface Drainage Design* [NAVFAC 2018]).

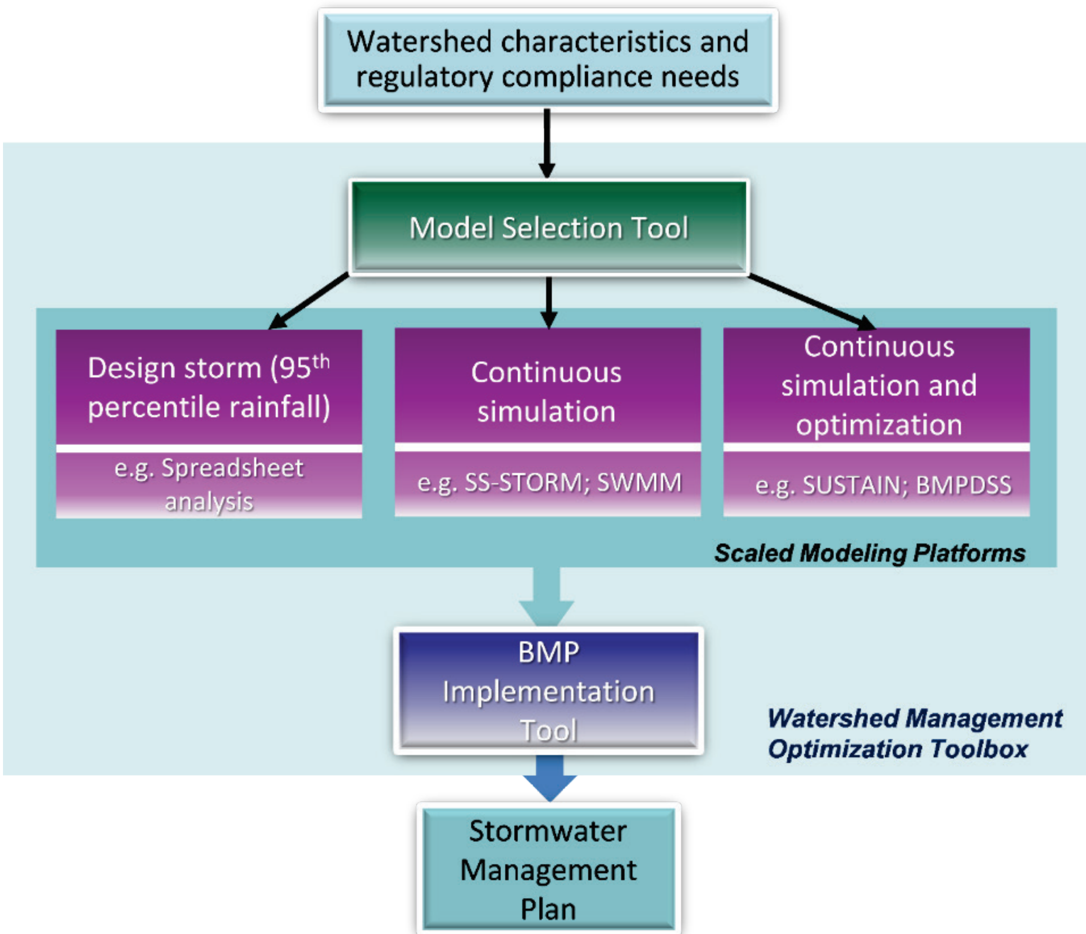
2 Methodology Description

This chapter provides a detailed discussion of individual SMOT components, including input data compilation, MST, Scaled Modeling Platforms, and the BMP Sizing Tool. The complete process of complying with applicable stormwater regulations is illustrated through subsequent case studies.

2.1 Methodology overview

Figure 2-1 shows the four major components of SMOT, including: (1) the compilation of input data to the toolbox, (2) MST for recommendation of cost-effective modeling approach, (3) detailed modeling platforms, and (4) the BMP Sizing Tool for implementation and tracking.

Figure 2-1. Overview of the Stormwater Management Optimization Toolbox.



The full suite of SMOT components is intended to provide installations with a comprehensive toolset that can streamline the stormwater compliance process through cost-effective BMP sizing. MST was refined as part of the Phase I demonstration, which was completed in 2015. The scaled model platforms are publicly available stormwater BMP models, with the most recent versions of EPA SWMM (USEPA 2015) and EPA SUSTAIN (USEPA 2009b) used in this demonstration. The BMP Implementation Tool was refined for the two installations assessed as part of this demonstration.

2.2 Methodology development

Previous studies have demonstrated that the choice of modeling tools can substantially influence BMP sizes. EISA compliance studies at Barksdale and Minot AFBs demonstrated that different installations and associated environments warrant a different modeling approach. Additionally, an AFCEC study comprehensively investigated how watershed conditions (e.g., soils, rainfall, and drainage network) may impact the required BMP sizes following the two EISA compliance options (Tetra Tech 2013a). The investigation also analyzed the threshold above which the optimization techniques are expected to result in significant cost savings. These efforts were consolidated into a draft version of an MST that could guide a design engineer to choose the most cost-effective modeling tool at an AFB. Phase I of this demonstration built on the preliminary MST and refined the tool methodologies for the Continuous Simulation (CS) and CS+O BMP estimates. MST was stress tested to confirm that the appropriate modeling methodology was selected for 45 installations. Phase II of the demonstration furthers the validation of MST by comparing the MST against detailed modeling platforms at APG and NAS Key West. The detailed modeling platforms (EPA SWMM and SUSTAIN) are publicly available and approved technologies.

2.3 Advantages and limitations of the technology/methodology

As evidenced in previous discussions, the main advantage of SMOT is that it is the first comprehensive toolset that can effectively integrate all steps in stormwater management into a streamlined process, while achieving cost-effective results. With SMOT, an installation can identify the most cost-effective BMP sizing approach using a limited amount of preliminary data collection, carry out the modeling process through designated modeling tools, and then import the results into the BMP Sizing Tool.

One limitation of SMOT is that the full integration of the continuous simulation coupled with optimization modeling approach is currently not available in the Excel environment. Research efforts are under way to develop an Excel-based version of the SUSTAIN model, which is capable of both continuous simulation-only and continuous simulation coupled with optimization modeling analyses. It is expected that the Excel-based SUSTAIN model, once completed, can be incorporated into the SMOT framework. This means that all three detailed modeling platforms (design storm, continuous simulation-only, and continuous simulation coupled with optimization) can be operated within SMOT.

The alternative to SMOT is a scattered, uncoordinated, and non-optimized approach for planning BMPs to achieve stormwater EISA 438 regulation compliance. Under the current system, the modeling approach chosen for BMP sizing analysis is mostly dependent on the expertise of the modeler, as the potential consequences from various modeling approaches are not fully recognized. In addition, BMP representations and assumptions during the modeling analysis may not be accurately and completely transferred to engineers in charge of construction and maintenance, resulting in less desirable management results. The lack of practical and efficient tracking and reporting mechanisms also hinders stormwater regulation compliance efforts.

Another limitation to SMOT is its use for regulatory compliance beyond EISA section 438. Stormwater regulations to which an installation is subject can vary from EISA section 438 only, to EISA section 438 and TMDL, to EISA section 438 and TMDLs for regional, state, or local MS4s permits. EISA section 438 is applicable to all installations by default. Modeling solely for EISA section 438 is not advised when other TMDL and/or MS4 regulations are present within the watershed or receiving streams. When an installation is subject to TMDL regulations, a watershed model with water quality representation is necessary for carrying out the analysis to demonstrate progress towards addressing the applicable TMDLs. Modeling BMP sizes solely for EISA 438, does not address the requirement to demonstrate progress towards addressing the applicable TMDL. Without considering TMDL behaviors, there is a risk that the installation will not fulfill regulatory requirements that have been established by the regulatory agency and the installation.

SMOT is designed to question the stormwater manager to include any 303d, TMDL, or other regulatory requirements that impact stormwater. If the installation determines that EISA section 438 is the only relevant driver that they are choosing to plan to, SMOT can be used to size optimal BMPs. If the installation determines that other water quality drivers exist (TMDL, MS4, etc.), SMOT will direct those users to pursue more detailed modeling. SMOT only addresses the difference in BMP size as it relates to EISA 438 compliance, not the nuanced requirements for pollutants of concern. The presence of a TMDL, impairment, or regulatory requirement automatically excludes the design storm (DS) modeling approach when using the MST. SMOT will then do a simplified CS or CS+O approach, depending on the MST results that will account for TMDL requirements but not address the "progress." This can only be achieved through using the full-scale modeling approaches from CS (SWMM) or CS+O (BASINS). If SMOT is used to size BMPs when there is a regulatory driver beyond EISA section 438, the installation is at risk for not meeting the long-term requirements as they relate to the pollutants of concern.

The BMP Sizing Tool created for SMOT offers a user planning-level sizing and configuration for BMPs. SMOT has only been validated for EISA section 438 compliance and has not been validated for the purpose of meeting fate and transport requirements associated with TMDLs. SMOT can be used to help identify the modeling approach for an installation to use but to base BMP sizing for compliance outside of EISA section 438 is not recommended.

Overall, SMOT presents a solid package that DoD installations can rely on for comprehensive support to stormwater regulation compliance to EISA section 438. The toolset is able to choose a cost-effective modeling approach for sizing BMPs in an installation, provide guidance on detailed modeling analysis, guide efficient implementation, and then provide a tracking and accounting tool for long-term stormwater management. As limitations in detailed modeling capabilities are overcome, the toolset can provide a completely streamlined process for cost-effective stormwater regulation compliance support to all DoD installations.

3 Performance Objectives

Table 3-1 lists the performance objectives for the Phase II SMOT demonstration and include both quantitative and qualitative measures. Narrative descriptions are provided at the end of each objective, highlighting its relevance to the technology demonstration and validation. Quantitative objectives in the table are based on results from the Phase I demonstration study and modeling experience. Qualitative objectives were established for the purpose of facilitating installation-wide implementation of SMOT.

Note that Table 3-1 uses several abbreviations to facilitate the discussion; Table 3-2 lists the definitions for these abbreviations.

Table 3-1. Demonstration Validation Performance Objectives and Descriptions.

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
1. The MST component of SMOT can accurately choose the most cost-effective modeling approach at the two selected installations	1.1. The continuous simulation-only approach is the most cost-effective at Installation #1 (APG) 1.2 The continuous simulation coupled with optimization approach is the most cost-effective at Installation #2 (NAS Key West) 1.3 MST accurately identifies the most cost-effective modeling approach at both installations	Continuous hourly rainfall data Hydrologic Soils Group (HSG) composition Soil infiltration rate Contour Drainage network Development plan	For Installation #1, BMP footprint areas following the continuous simulation-only and continuous simulation coupled with optimization approaches are within 10% of each other For Installation #1, BMP sizes following continuous simulation-only is at least 10% smaller than the design storm approach For Installation #2, BMP size following the continuous simulation coupled with optimization approach is at least 10% smaller than the other two approaches
The objective is to demonstrate that the MST component of SMOT can accurately choose the more cost-effective modeling approach for BMP sizing at the two selected installations (Installation #1 and Installation #2). The primary metric in this objective is the accuracy of the tool in the modeling approach prediction at the two sites. The success criterion consists of three segments: (1) detailed modeling analysis demonstrates the continuous simulation approach is the most cost-effective at Installation #1, (2) detailed modeling analysis demonstrates that the continuous simulation coupled with optimization approach is the most cost-effective at Installation #2, and (3) the MST component accurately chooses continuous simulation-only approach for Installation #1 and continuous simulation coupled with optimization approach for Installation #2. Data requirements for the two installations include continuous rainfall record, elevation contours, drainage network, land use, and development plan. To fulfill this objective, detailed modeling analyses were be carried out at the two installations. The detailed modeling analysis consisted of design storm, continuous simulation-only, and continuous simulation coupled with optimization simulations. Detailed watershed representation was built for the latter two simulation approaches. The detailed watershed representation includes subwatershed delineation, flow routing network, and the representation of hydrologic response units (HRUs). BMPs were sized following each of the three modeling approaches. The BMP modeling results were compared against each other to verify MST predictions. It was expected that MST will choose the accurate modeling approach at both installations. The process can be expressed as follows: $\min (A_{MST\_DS\text{-}i}, A_{MST\_CS\text{-}i}, A_{MST\_CS+OPT\text{-}i})_{i=1,2} \rightarrow SM_{MST\text{-}i}$ (1) $\min (A_{VAL\text{-}DS\text{-}i}, A_{VAL\_CS\text{-}i}, A_{VAL\_CS+OPT\text{-}i})_{i=1,2} \rightarrow SM_{VAL\text{-}I}$ (2)			

<table>
<tr><th>Performance Objective</th><th>Metric</th><th>Data Requirements</th><th>Success Criteria</th></tr>
<tr><td colspan="4">with the objective of:
$A_{VAL\_CS-1} \le 0.9 * A_{VAL-DS-1}$ and $ABS((A_{VAL\_CS-1} - A_{VAL\_CS+OPT-1}) / A_{VAL\_CS-1}) \le 10\%$ (3)
$A_{VAL\_CS+OPT-2} \le 0.9 * A_{VAL-DS-2}$ and $A_{VAL\_CS+OPT-1} \le 0.9 * A_{VAL\_CS-2}$ (4)
where SM_{MST-i} is the selected modeling approach resulting from the MST assessment at installation *i*. A_{MST_DS-i}, A_{MST_CS-i}, and $A_{MST\_CS+OPT-i}$ are the relative BMP footprint sizing requirements calculated by MST at installation *i*. SM_{VAL-i} is the selected modeling approach resulting from the validation modeling assessments (i.e., SWMM, SUSTAIN). $A_{VAL-DS-i}$, A_{VAL_CS-i}, and $A_{VAL\_CS+OPT-i}$ are the BMP footprint sizing requirements calculated by the validation modeling assessments at installation *i*, and *i* is the index for the two demonstration installations, with *i*=1 for Installation #1 and *i*=2 for Installation #2.
This objective further verifies the MST component of SMOT through detailed modeling analyses. In comparison to Phase I planning-level demonstration and verification of the MST component, the verification here accounts for more development details on an installation.</td></tr>
<tr><td colspan="4">*Qualitative Performance Objectives*</td></tr>
<tr><td rowspan="3">2. Data Availability</td><td>2.1. Degree to which SMOT is able to run using readily available national datasets</td><td>Continuous hourly rainfall data
Soils HSG composition
Composite soil infiltration rate
Regulatory requirements</td><td>Minimum data requirements by the tool (rainfall and soils) can be readily downloaded from the websites of corresponding agencies</td></tr>
<tr><td>2.2. If local data are required or useful, degree to which data are typically available</td><td>Local municipal level stormwater regulations
Contour
Drainage network
Development plan</td><td>Data are available for local municipal stormwater regulation
Data are available for contour, drainage network, and development plan with installation geodatabase</td></tr>
<tr><td>2.3 If local data collection is necessary, degree to which resources are required to acquire such data</td><td>No local data collection is needed for verifying the MST component nor for the demonstration of SMOT as a whole</td><td>Not applicable</td></tr>
<tr><td colspan="4">Input data to SMOT include the continuous hourly rainfall record, soils HSG composition, composite soils infiltration rate, and regulatory requirements. Among the input data, the hourly rainfall record, soils HSG composition, and soils infiltration rate can be readily downloaded from the National Climate Data Center (NCDC) and U.S. Department of Agriculture (USDA) websites, respectively. The composite soils infiltration rate for an installation can be estimated through the area-weighting approach. If a detailed watershed modeling approach is recommended, then additional watershed data including contour, drainage network, and development plans are required. The additional data are often available through generic installation geodatabases.
In addition to the rainfall and soils information, the regulations that a base is subject to can vary from EISA section 438 only, to EISA section 438 and Total Maximum Daily Load (TMDL), to EISA section 438 and TMDL and other local Municipal Separate Storm Sewer System (MS4s) permits. As the EISA section 438 is applicable to all installations by default, the TMDL and MS4 regulations, when present, can be identified through the state and local government websites. There is no need to conduct site visits and collect local data to run the model.</td></tr>
<tr><td rowspan="2">3. Ease of Use</td><td>3.1. Resources and expertise required to set up SMOT for typical military installations</td><td>Time needed to prepare input data for SMOT components
Feedback collected through a Likert survey and communication during hands-on training of the Toolset</td><td>Base or base-designated engineer(s) with 1 to 5 years of experiences in stormwater management can start using the model in less than 4 hours
The collection and preparation of input data for the MST component takes no more than 3 days for base engineers with basic knowledge about GIS data processing
The collection and preparation of input data for detailed modeling techniques and the BMP Sizing Tool will take no more than a week for base engineer(s)</td></tr>
<tr><td>3.2. For obtaining output variables of interest, the amount of</td><td>Time needed to run SMOT at an installation</td><td>The running time for the MST component will be about one minute</td></tr>
</table>

Performance Objective	Metric	Data Requirements	Success Criteria
	time to run the model is reasonable		The running time for continuous simulation-only (when necessary) and the BMP Sizing Tool will take 2 minutes The running time for continuous simulation coupled with optimization (when necessary) will take up to 5 hours
	3.3. Degree of expertise required to interpret the results of the model	Time needed to identify the recommended modeling approach at an installation Time needed to retrieve BMP sizing requirements from continuous simulation and continuous simulation coupled with optimization approaches (when applicable) Feedback collected through a Likert survey and communication during hands-on training of the Tool	Base or base-designated engineer(s) with 1 to 5 years of experiences in stormwater management can directly identify the recommended modeling approach through the tool recommendations Base engineers can understand the rationale behind the recommendation with less than 1-day's training Base engineers can readily interpret results regarding recommended BMP size and identify the most cost-effective approach from the continuous simulation-only and the continuous simulation coupled with optimization approach in less than 1-day's training
	3.4. For any given intended user, the training necessary to setup, parameterize, and run the model is reasonable	Time needed to set up, parameterize, and run SMOT Feedback collected through a Likert survey and communication during hands-on training of the Tool	Base or base-designated engineer(s) 1 to 5 years of experiences in stormwater management can set up, parameterize, and run SMOT in less than 2 weeks on a per question basis Base engineers with 5 or more years of experiences in stormwater management can set up, parameterize, and run SMOT in one week on a per question basis
	3.5. Degree to which the model needs to be calibrated and validated at a new application site and the ease of doing so is reasonable	Implementations of MST at a new application site do not involve calibration or validation activities	Not applicable
SMOT was developed in a Microsoft Excel (Version 2010) environment with a user-friendly interface. The toolset retains self-explanatory interfaces to guide users in preparing the necessary input data, and help information is provided throughout the user interface for additional guidance. It is expected that the downloading and preparation of input data (e.g., rainfall, soils, and regulatory requirements) to the MST component of SMOT may take less than 3 days for base engineers with 1 to 5 years of stormwater experiences. The time could be as short as 1 day for experienced engineers with over 5 years of experiences. Once the data are processed, running the MST component will take less than one minute, and base engineers can directly identify the recommended modeling approach for further BMP sizing analyses. Efforts involved in detailed modeling platforms of SMOT vary depending on the modeling approach recommended by MST. When the design storm approach is recommended, SMOT can estimate BMP sizes using built-in sizing capabilities, and the calculation can be done in one minute. When continuous simulation-only approach is recommended, the running time of the model could be up to 3 minutes depending on watershed sizes. If the continuous simulation coupled with optimization approach is recommended, the optimization run process could take up to 4 hours. After the modeling results are entered into the BMP Sizing Tool, each run of the BMP Sizing Tool will take 2 to 3 minutes. Throughout the demonstration, personal communication with base engineers and a Likert type of survey were employed, to the extent possible, to determine the success of relevant metrics. All items were rated using a 5-point Likert scale. The minimum acceptable threshold for responses cannot be below a 2. The minimum acceptable average threshold for all scores cannot be below a 3.5. A sample of the survey is attached to this Demonstration Plan as Appendix B.			

Table 3-2. Abbreviations used in Tbl. 3-1.

Abbreviations	Definition
A	BMP surface area (sf)
CS	Continuous simulation analysis
DS	Design storm analysis
OPT	Optimization analysis
P	Probability
SM	Selected Model; the modeling approach identified
VAL	Validation analysis; the actual modeling analysis with established models

4 Site Description

The Phase II demonstration of SMOT showcases the capability of the toolbox in providing comprehensive stormwater regulation compliance support at APG and NAS Key West. The MST component of SMOT was further verified during this round of demonstration. All major components of SMOT, including MST, detailed modeling analyses, and the BMP implementation tools, were demonstrated at the two sites. Site selection methodology and selection results for the two demonstration sites were presented in the July 2015 memorandum (Subject: "Stormwater Management and Optimization Toolbox Site Selection Memorandum/ Table 1 Performance Objectives Phase 2").

4.1 Site selection

The full capacity of SMOT was demonstrated at two installations that have differing site characteristics and ultimately resulted in different modeling methodologies required for compliance: one where the CS only approach is recommended and the other where the Continuous Simulation coupled with Optimization (CS+O) approach is recommended. No installation was selected separately for the DS approach due to the fact that the DS approach is the most straightforward approach among the three detailed modeling approaches. Additionally, demonstration of the other two approaches automatically includes the demonstrations of the DS approach through comparisons.

The criteria for selecting the two demonstration sites out of the 45 installations included in the Phase I demonstration were generated as part of that effort. Table 4-1 lists the primary and secondary site selection criteria. The criteria are presented in two stages: (1) primary criteria, which are based on quantitative results yielded from the Phase I analysis (these are used to identify eight candidates for final consideration) and (2) secondary criteria, which are comprised mostly of qualitative information about the individual installations, but were important for final selection. The individual parameters are summarized as follows:

- *MST recommended model approach (Primary Criteria)*: In Phase I, each installation was evaluated by MST and unit-area modeling tools to predict the full-scale model approach that would result in the smallest set of BMPs. The candidate bases were categorized as DS, CS, and CS+O to ensure that only CS and CS+O bases were considered.

- *Cost savings potential (Primary Criteria)*: The results of the analyses performed in Phase I were used to estimate the relative costs of each BMP sizing approach. Only those installations with the highest cost difference between DS, CS, and CS+O were considered for further evaluation in Phase II.
- *Regulatory requirements (Secondary Criteria)*: Numeric targets for stormwater capture or treatment drive the need for modeling analysis. To ensure maximum future flexibility of SMOT, a variety of regulatory drivers are desired.
- *BMP retrofit requirement (Secondary Criteria)*: While EISA is, by DoD definition, triggered only by new development, other regulatory drivers require BMP retrofits to meet water quality improvement targets. Since these targets can drive a range of outcomes/goals, it is important to include a variety of requirements to fully demonstrate SMOT.
- *Master plan indicates future development (Secondary Criteria):* Since future development drives the need for EISA compliance, SMOT is best demonstrated at installations with future expansion plans.
- *Willingness and data availability (Secondary Criteria):* Developing installation-scale modeling analyses at an installation requires active participation and sound datasets. It was imperative that the final two installations were prepared to fully engage in the process.
- *Clean Water Act Service Steering Committee (CWASSC) and ESTCP Recommendations (Secondary Criteria):* Identification of priority sites for the CWASSC and ESTCP are taken into consideration to provide valuable and applicable information from the full demonstration of SMOT. The final two selected installations were those that have been approved by the CWASSC and ESTCP.

Table 4-1. Site selection criteria for demonstration of SMOT.

Selection Stage	Parameter	Preferred Values	
		Installation #1 (APG)	Installation #2 (NAS Key West)
Primary	MST recommended model approach	CS	CS+O
	Cost savings potential	High	High
Secondary	Regulatory requirements	1 Installation with EISA only 1 Installation with EISA+TMDL	
	BMP retrofit requirement	n/a	High
	Master plan indicates future development	Yes	Yes
	Willingness and data availability	High	High
	CWASSC and ESTCP recommendations	High	High

Final base selection for the Phase II demonstration was determined from the presented site selection criteria when compared to individual site characteristics and MST results.

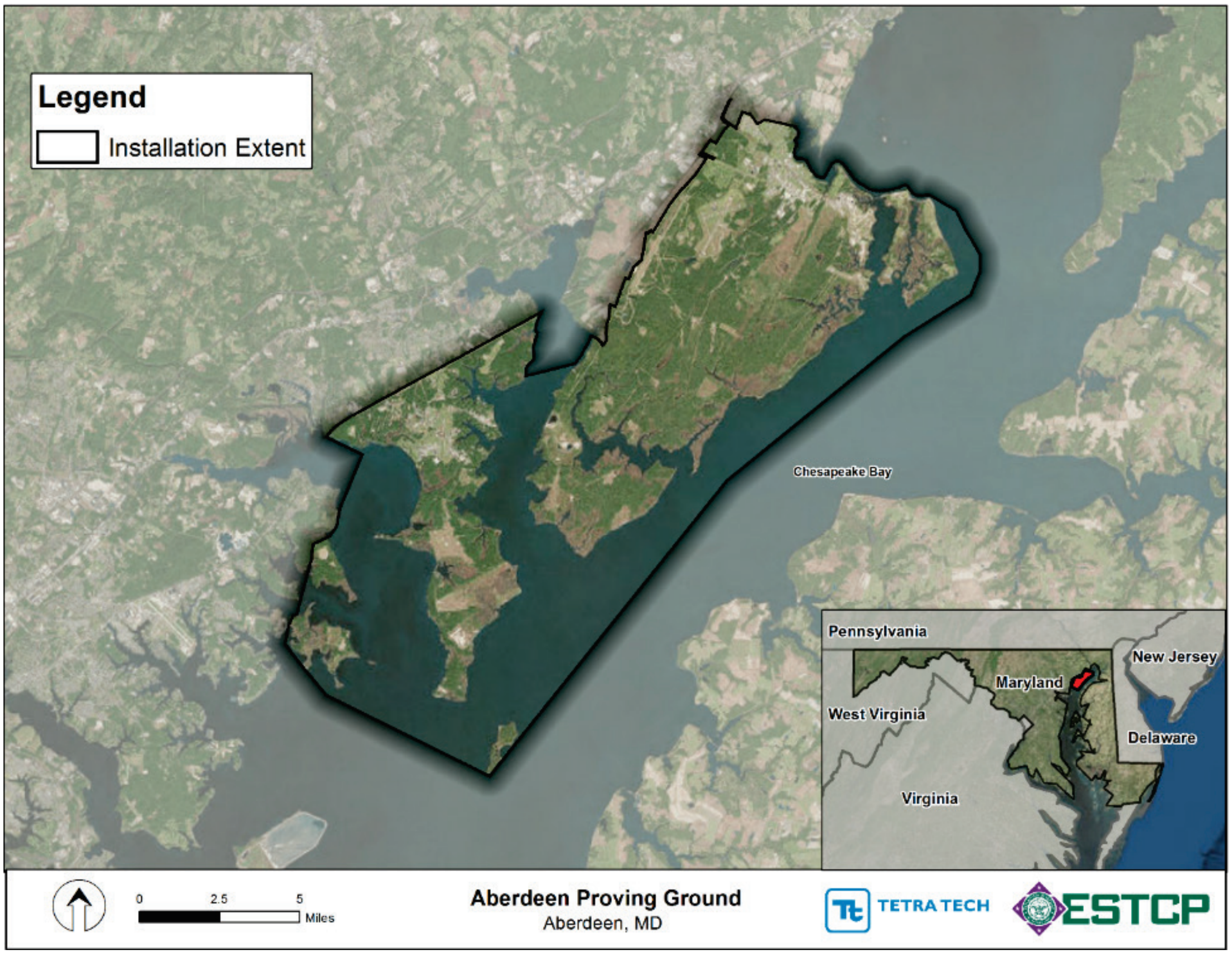
Results from MST indicate that Installation #1, APG, has a high potential for cost savings by using the CS method. APG is also subject to both EISA requirements and the Chesapeake Bay TMDL for Nitrogen, Phosphorus, and Sediment (USEPA 2010), as well as the Maryland Phase II Watershed Implementation Plan, which has established limits on nitrogen. APG also has data necessary for model development that are available and willingly shared, as week as a masterplan that indicates future development. Lastly, APG has been approved for inclusion in this demonstration by the CWASSC and ESTCP.

Conversely, results from MST indicated that Installation 2, NAS Key West, could achieve a high potential cost savings by using the CS+O method, thereby satisfying the primary site selection criteria. Additionally, NAS Key West is subject to EISA requirements, has the necessary data for model development that are available and willingly shared, and has a masterplan that indicates future development. NAS Key West has also been approved for inclusion in this demonstration by the CWASSC and ESTCP.

4.2 Site location and history

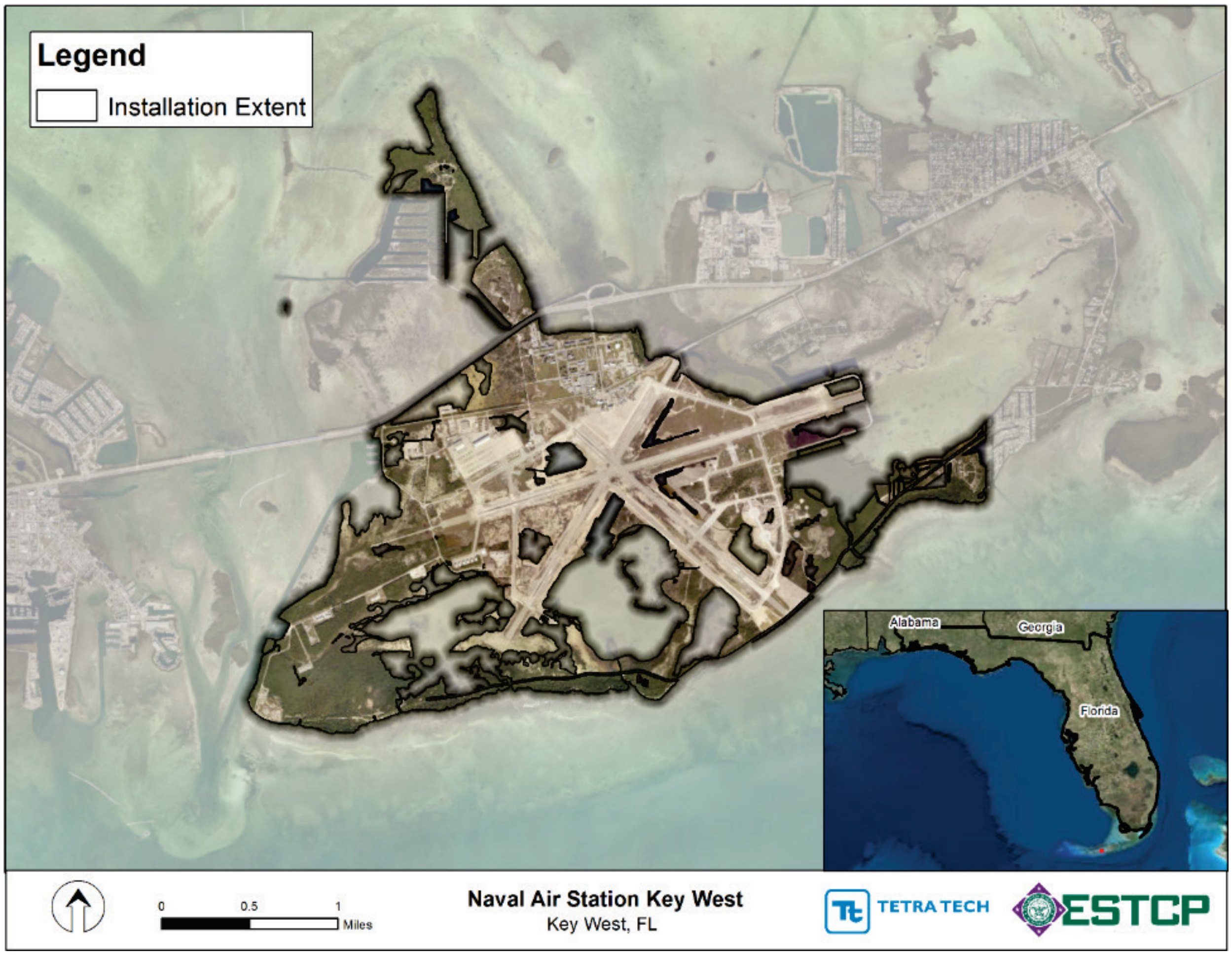
APG is a U.S. Army facility located within Harford County, Maryland covering 114 square miles. The site is partially bordered by the Chesapeake Bay to the east. The demonstration covered the extent of the entire base (Figure 4-1).

Figure 4-1. Aberdeen Proving Ground site and areas of interest.



NAS Key West is located on the Boca Chica Key covering approximately 26 square miles. NAS Key West is in Monroe County, Florida and is bordered on all sides by the Atlantic Ocean. The demonstration covered the entire base (Figure 4-2). The demonstrations on these two did not require any disruption or development of the base. They serve as example sites to test several modeling platforms. The models required information regarding soil composition, local rainfall data, storm drain infrastructure, and a Digital Elevation Model (DEM).

Figure 4-2. NAS Key West site and selected subcatchment area.



4.3 Local regulatory drivers

Depending on their respective geographical locations, individual bases are faced with different stormwater regulations. The two installations selected for the Phase II demonstration reflect this diversity. APG is subject to both EISA requirements and the Chesapeake Bay TMDL for Nitrogen, Phosphorus, and Sediment (USEPA 2010), as well as the Maryland Phase II Watershed Implementation Plan, which has established limits on nitrogen. NAS Key West is subject to EISA requirements, as well as the TMDL for Mercury in 102 Florida Waterbodies; however, stormwater was not deemed a contributing source of Mercury and is not applicable for the purposes of this demonstration (USEPA 2012).

4.4 Site characteristics

APG is located in a coastal region with relatively flat, mild topography. APG experiences four distinct seasons and lies within the humid subtropical zone (hot and humid summers, and mild winters). The depth of the 95th percentile storm, as calculated using a 30-year continuous observed rainfall record from a proximal rain gauge (NCDC 2017) is 1.79 in. An analysis of underlying soils indicated that APG is composed of approximately 15% HSG B, 61% HSG C, and 24% HSG D (NRCS 2016). Figures 4-3 and 4-4 illustrate the HSG breakdown across APG.

As detailed in chapter 3, "Performance Objectives," regional climate, depth of the 95th percentile storm, and HSG present at APG are important site characteristics that were incorporated to select this installation as a candidate site.

Figure 4-3. HSG and impervious area composition for APG.

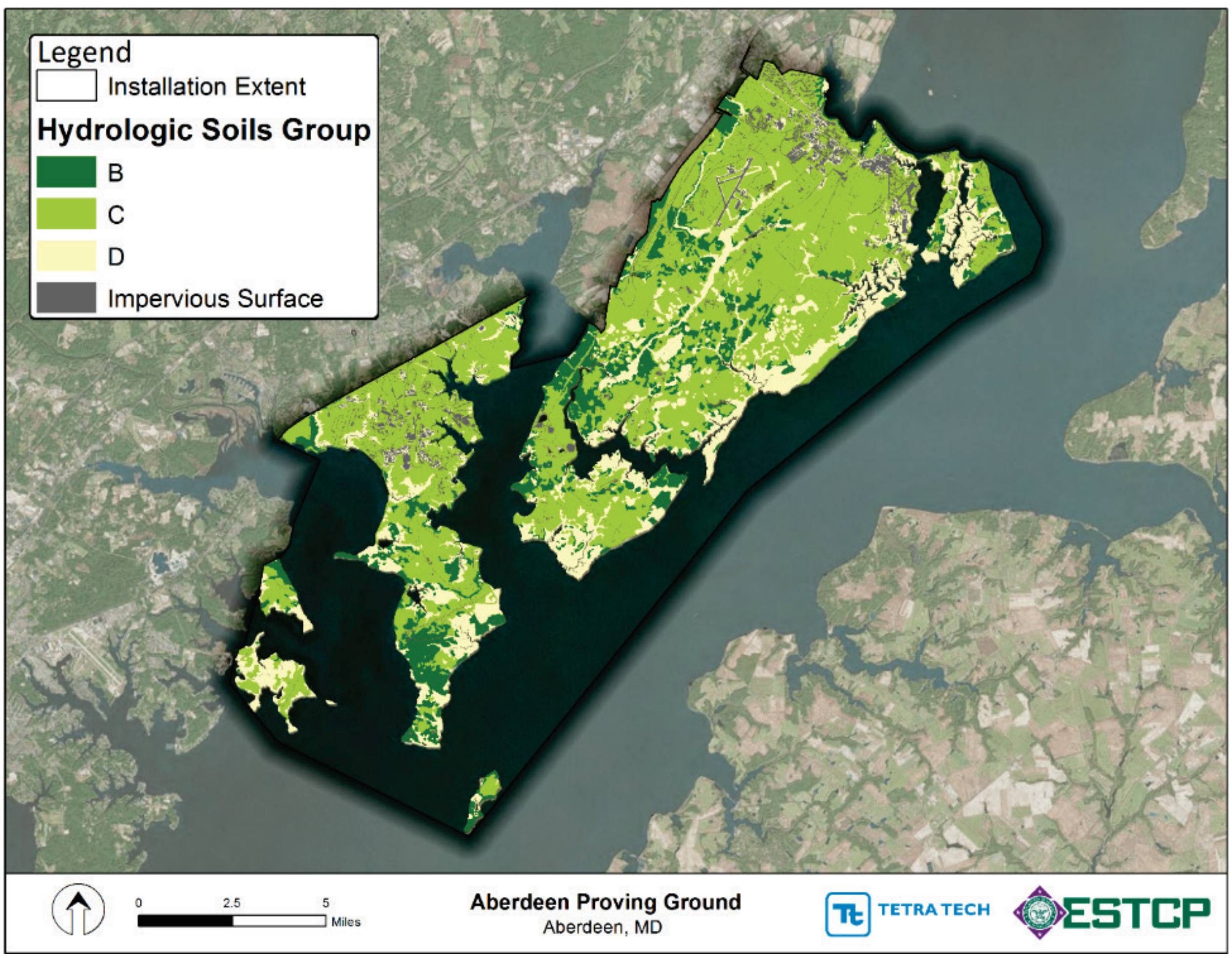
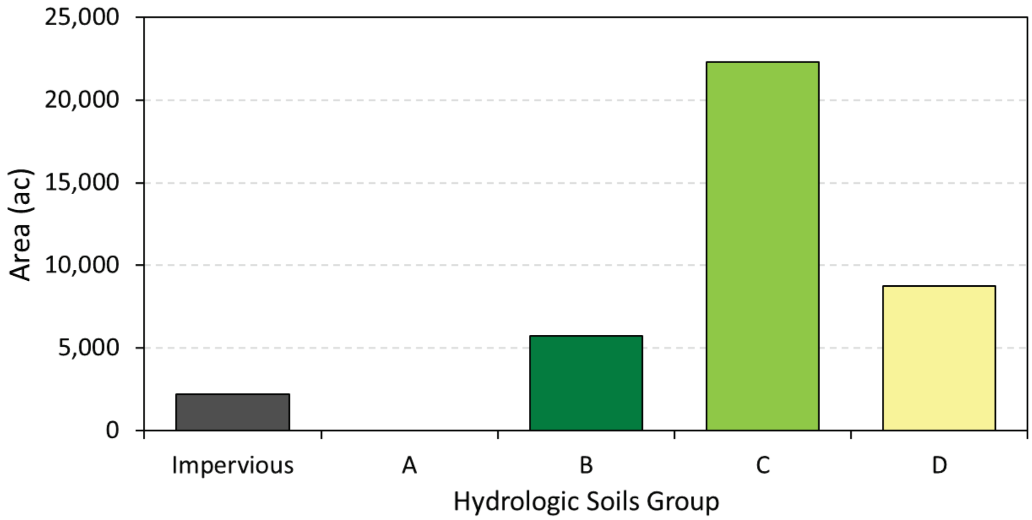


Figure 4-4. Composition of HSG and impervious area for APG.



NAS Key West is also located in a coastal region with relatively flat, mild topography, but it experiences two distinct seasons (wet and dry) and lies within the tropical savanna climate zone. The depth of the 95th percentile storm, as calculated using a 30-year continuous observed rainfall record from a local rain gauge (NCDC 2017) is 2.26 in. For NAS Key West, soil analyses showed a composition of approximately 40% HSG A soils and 60% HSG D soils (NRCS 2016). Figures 4-5 and 4-6 show the HSG breakdown across NAS Key West.

As detailed in chapter 3, "Performance Objectives," regional climate, depth of the 95th percentile storm, and HSG present at NAS Key West are important site characteristics that were incorporated to select this installation as a candidate site.

Figure 4-5. HSG and Impervious Area Composition for NAS Key West.

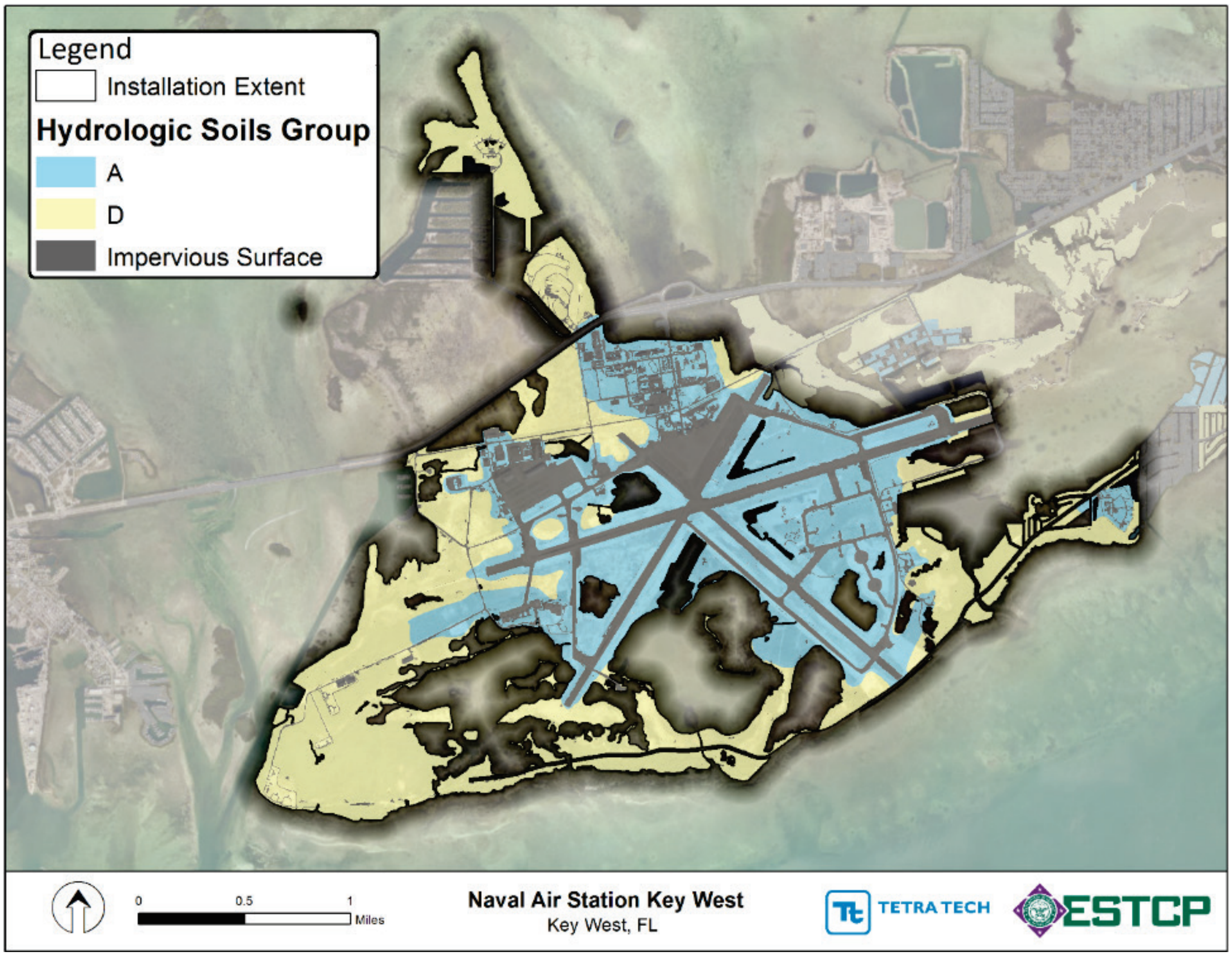
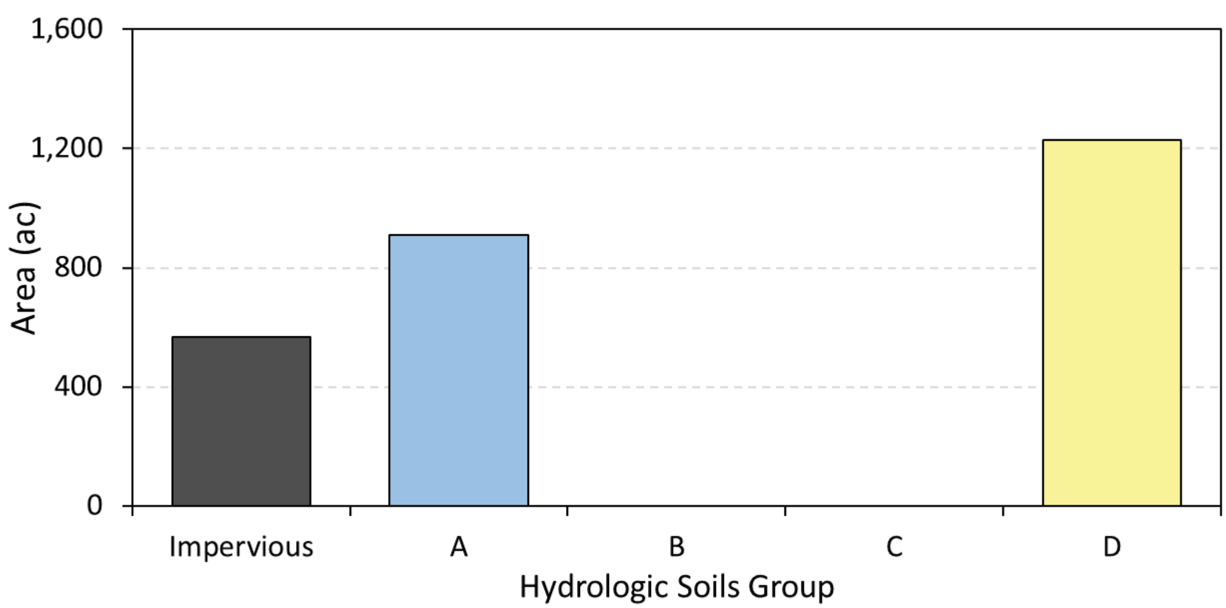


Figure 4-6. Composition of HSG and impervious area for NAS Key West.



5 Test Design

This chapter provides an overview of the demonstration methodology for the full capabilities of SMOT at APG and NAS Key West. This demonstration was designed to be more than a typical implementation of SMOT at an installation. There is the additional goal of verifying the MST component of SMOT against detailed modeling results. In addition, it is intended that SMOT demonstrations at the two selected sites serve as examples for stormwater regulation compliance at other DoD installations.

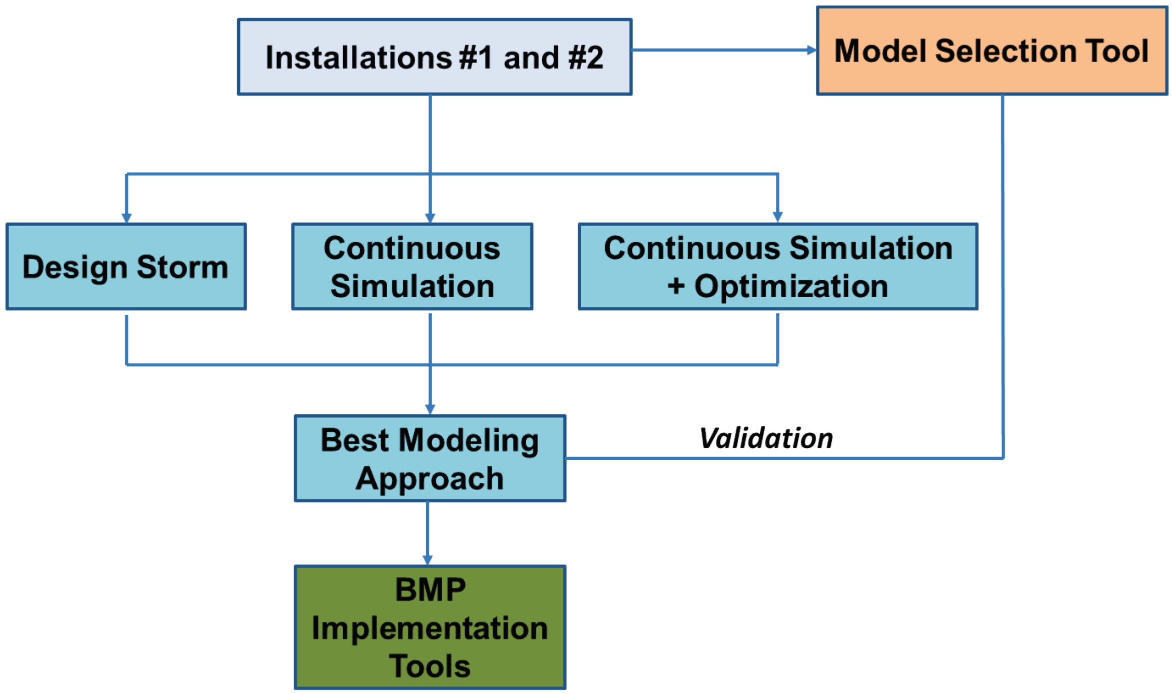
Demonstration of SMOT differs somewhat from the demonstrations of conventional resource conservation projects. Conventional resource conservation projects often involve physical construction and activities, sampling of hydrological and water quality parameters before and after the construction, and subsequent data analyses for verification of the project effectiveness. In comparison, demonstration of SMOT does not involve project construction or monitoring activities, but instead compares BMP sizing model results of the simplified Model Selection Tool to those of trusted, USEPA-approved model platforms. As a result, the test design of SMOT demonstration mainly consists of activities related to stormwater modeling.

This chapter introduces test designs for the SMOT demonstration. The test design discussion follows the same format as conventional resource conservation project discussions. Specific notes are made when certain subsections (e.g., sampling plan) are not applicable to the SMOT demonstration.

5.1 Conceptual test design

Full demonstration of SMOT consists of three main steps. In the first step, MST is implemented to obtain a recommended detailed modeling approach pursuant to the performance objectives. In the second step, detailed modeling analyses are performed for the watershed following the three modeling methods separately, and the results are used to verify the MST recommendation in the first step. Step three of SMOT includes the setup of BMP implementation tools for each installation. BMP sizing requirements following the detailed analysis in step two are used as input for the BMP implementation tools. At the end of the SMOT demonstration process, each of the two selected installations had a set of BMP implementation tools ready for guiding future development and cost-effective BMP implementation activities to comply with applicable stormwater regulations (Figure 5-1).

Figure 5-1. Overview of the conceptual experimental design for demonstration and stress-testing of the Model Selection Tool.



Three separate detailed modeling methods were performed at the two selected installations for BMP sizing analyses (DS, CS, and CS+O). Spreadsheet calculation methods were used for the DS modeling method analysis. SWMM model was used for the CS modeling method analysis. The SUSTAIN model was used for the CS+O modeling method analysis. A comparison among the three BMP sizes following the detailed modeling approaches helped to determine the most cost-effective modeling approach and to validate MST recommendations. MST was able to accurately choose the appropriate modeling approach at both installations. Table 5-1 summarizes the performed modeling scenarios.

Table 5-1. Detailed modeling scenarios to be analyzed at the two selected installations during the demonstration and verification of SMOT.

Modeling Methods	Model Selection Tool Analysis	Detailed Modeling Analysis
DS	Built-in Algorithms	Spreadsheet calculation
CS	Simplified Continuous Simulation Tool	SWMM
CS+O	Heterogeneity Index Curve	SUSTAIN

The conceptual test design at APG used SUSTAIN to show that CS was the most appropriate modeling approach, matching the results recommended by MST. The modeling strategy used to confirm this demonstrated that, under various development scenarios, siting of BMPs on different soil types does not yield significant cost savings or increases in BMP performance. This demonstrates that an optimization approach that varies BMP size (to mitigate the runoff effects of the newly created impervious area) over many locations with varying sizes across a region with homogenous underlying soils is unnecessary to achieve significant cost savings.

The conceptual test design for NAS Key West used SUSTAIN to show that CS+O is the most appropriate modeling approach, matching the results recommended by MST. The modeling strategy used to confirm this demonstrated that BMP location is relevant to BMP performance when considering underlying soil characteristics. This means that, in a predominantly heterogeneous HSG setting, an optimization approach that varies BMP size (to mitigate the effects of the newly created impervious area) over many locations with varying sizes across a region can achieve significant cost savings.

Subcatchment and subwatershed-scale simulations were developed with the SWMM and SUSTAIN models to simulate the hydrologic effect of new development and BMPs for selected areas of APG and NAS Key West. Development scenarios were generated to simulate potential actions that would trigger EISA requirements. Output from the continuous simulation models (with and without optimization) were compared to MST to confirm whether the same modeling method yielded cost savings (>10%). Due to the variability in the scale of development that may occur at an installation, the test included models at two scales: (1) subcatchment scale (approx. 100 acres) and (2) subwatershed scale (approx. 1,000 acres), to show that the results are consistent for all scales of modeling.

5.2 Baseline characterization and preparation

For conventional resource conservation projects, the baseline characterization of a watershed is an important step for establishing the hydrologic and water quality conditions before the restoration efforts so they can later be compared with those after the conservation efforts. The demonstration of SMOT at an installation does not involve the comparison of runoff conditions before and after a restoration project; however, it was necessary to compile installation data for modeling analyses to predict runoff condition changes before and after BMP implementation. This demonstration relies on the model output average annual flow volume (AAFV) from both

SWMM and SUSTAIN to quantify the predicted runoff condition change before and after redevelopment and BMP implementation.

Part of the baseline data for the two installations have been collected during the Phase I demonstration of the Model Selection Tool. Data includes installation area, climate region, distance to rain gauge, continuous hourly rainfall (30 years), HSG composition, composite infiltrate rate, and regulatory requirements. These data were used by MST to determine the most cost-effective modeling approach at an installation.

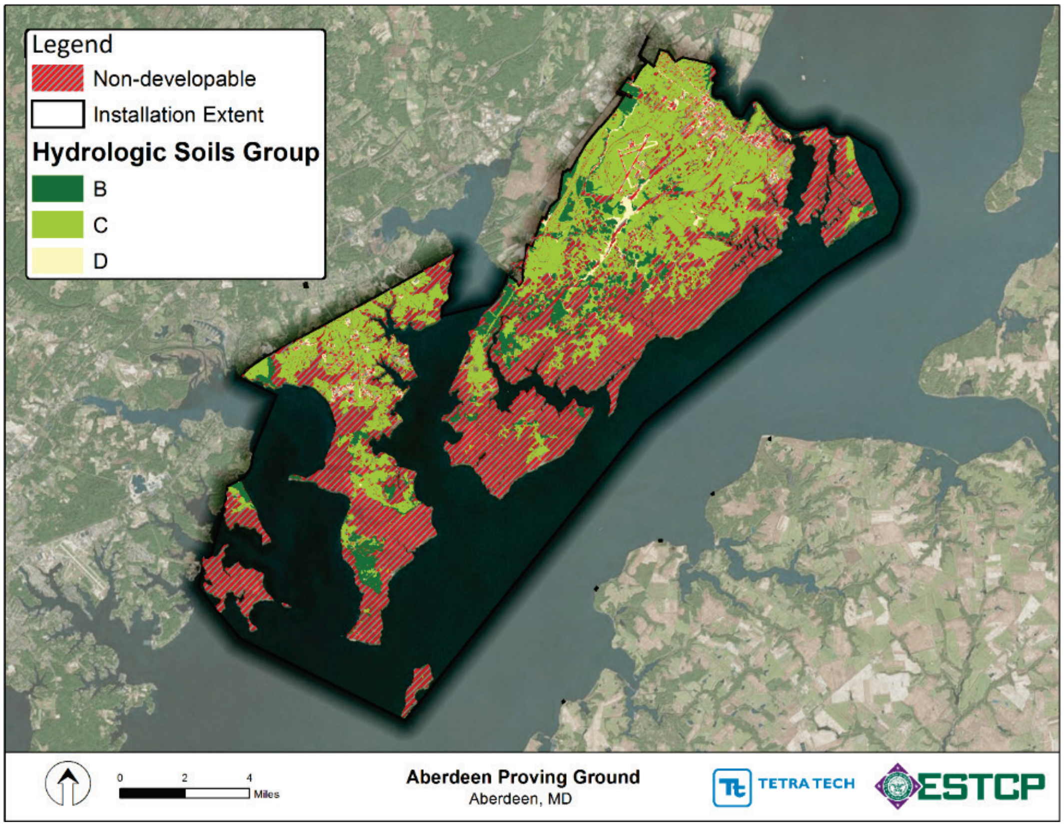
Additional installation characteristics data were collected at the two SMOT demonstration sites for the CS and CS+O modeling efforts including watershed land use, storm drain network, existing BMPs, DEM, and existing impervious area. To determine where proposed redevelopment projects could take place at each installation, an analysis of developable area was conducted to estimate the minimum BMP requirements that may be needed if EISA is triggered. This analysis created the conceptual development plan that is described in the following section.

5.3 Conceptual development Plan

Creation of a plausible conceptual development plan for each base relied on the establishment of areas of “developable land.” Not all areas within each base are feasible for development, including low-lying coastal areas that may be prone to regular flooding events. Consequently, these are generally poor choices for new construction projects.

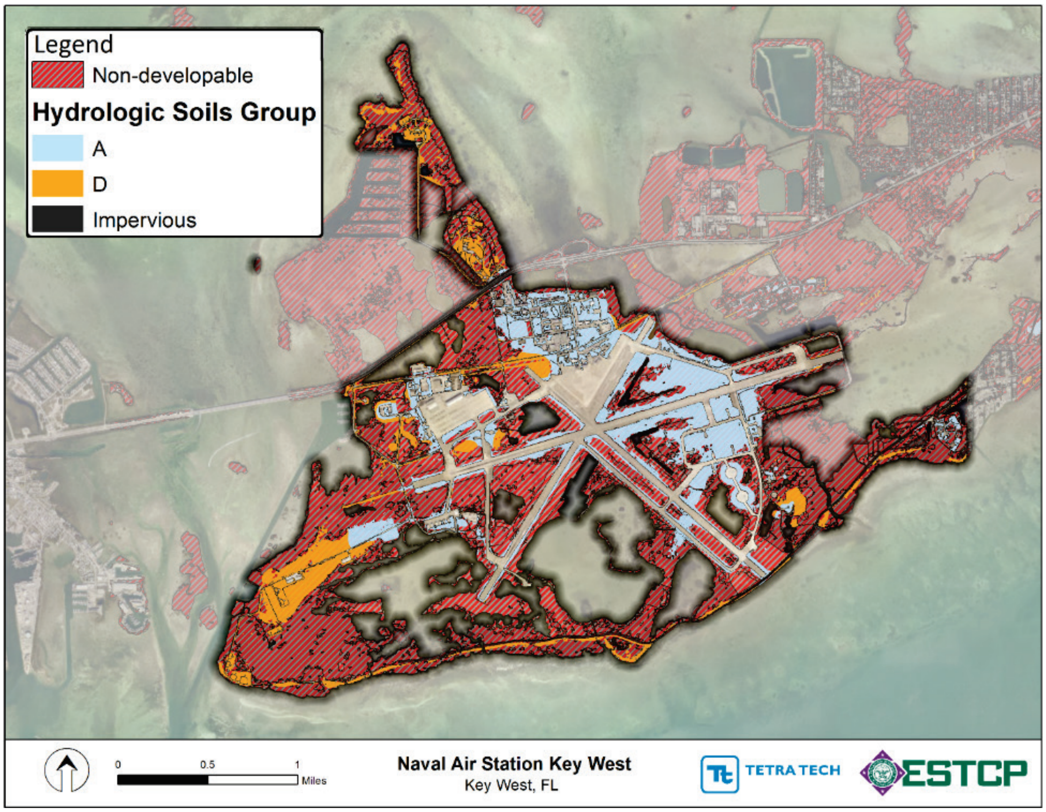
For APG, a geospatial layer that was provided by the installation was used to determine land that was likely ineligible for development. The source that provided the data was the U.S. Army Installation Geospatial Information and Services (IGI&S) Program, which indicated regions within the base as having either 1% or 0.2% annual flood risk. It was assumed that an annual flood risk less than 0.2% was the threshold for development; therefore, areas that did not meet this level of flood risk were determined to be ‘not recommended for development’ (i.e., non-developable land) (Figure 5-2).

Figure 5-2. HSG and non-developable areas for APG.



For Key West, a geospatial layer containing annual flood risk was not provided; instead, data from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center were used (NOAA 2017). Data from this source used statistical algorithms and historic precipitation patterns to determine the likelihood of flood waters inundating the land surface. Areas that were described in this dataset as those inundated during storm events with a "high degree of confidence" were assumed to be ineligible for development (Figure 5-3).

Figure 5-3. HSG and non-developable areas for NAS Key West.



5.4 Design and layout of technology and methodology components

Following compilation of site characteristics data, a comprehensive demonstration of SMOT was executed to support stormwater compliance efforts. As previously discussed, the demonstration involved all components of SMOT, i.e., MST, detailed modeling platforms, and BMP implementation tools.

The three major components of SMOT are closely connected. When applying SMOT at an installation, the first step is to compile baseline input data to the MST component, which recommends one of the three modeling methods for BMP sizing analysis at the base. If the DS approach is recommended, then the baseline data are sufficient for the setup of BMP implementation tools, and no additional data compilation is needed. If the CS or the CS+O is recommended, then additional watershed data as described in section 5.2 are needed for the detailed watershed model setup. The continuous simulation analyses (with or without optimization) yield the BMP sizing requirements in the base and the results are then used for setting up the BMP implementation tools.

The Phase II demonstration of SMOT adds one additional step of verification of the results from MST outside of a normal SMOT application to confirm MST's predictive capabilities. BMP sizing analyses are also carried out in this process using all three modeling approaches (instead of only the recommended modeling approach under a normal SMOT application). BMP sizing results were used to check whether the MST recommendations are accurate.

5.4.1 Application of the MST component

When applying SMOT at an installation, the first step is to implement MST to identify the most cost-effective model approach for specific installation characteristics. MST is designed as a user-friendly application for all DoD installations; it allows the user to conveniently input baseline watershed characteristics data. User-entered data are analyzed through the decision-tree, which compares the relative cost-effectiveness of the three modeling approaches, and the recommended modeling approach is provided with basic explanations of the logic behind the recommendation. For APG and Key West, MST was supplied with base-specific data (e.g., rainfall, HSG, and development area) and its output indicated the most effective modeling method.

5.4.2 Evaluation through the Design Storm Approach

The DS simulation approach is one of the three detailed modeling methods that can be applied at an installation. The DS simulation is executed through the spreadsheet-based analysis embedded into the Model Selection Tool. The development scenarios for each installation were used to estimate the required BMP sizes, rather than the representative 1-acre area used in Phase I.

One of the main inputs to the DS simulation approach is the 95th percentile, 24-hour rainfall depth. Technical guidance for identifying the 95th percentile rainfall depth and for estimating the required BMP sizes as specified by USEPA (2009b) were used and are incorporated in MST.

5.4.3 Evaluation through the Continuous Simulation Approach

The CS approach uses long-term, hourly climate data to simulate cumulative BMP treatment benefits. Physical rainfall-runoff processes were simulated through representations of HRU time series. As runoff from impervious surfaces were routed through BMPs, retention of water was simulated through infiltration and evapotranspiration processes. Long-term simulations allowed for the evaluation of impacts from factors such as land use, dry days, and varying soil infiltration rates.

The implementation of the CS approach involves several steps. The first step is to delineate subwatersheds based on contours and drainage networks that were provided by the installations. Subwatershed delineations provide the basis for evaluating runoff conditions before and after BMP implementation. The second step is to develop HRU runoff time series from various land uses in each subwatershed using EPA SWMM. Unit upland areas can be represented in SWMM with appropriate depression storage and infiltration parameters to reflect various land use and soil infiltration conditions. The third step is to estimate the pre- and post-development runoff conditions from the watershed. Post-development refers to the built-out land use conditions in the watershed; substituting pervious HRU time series in the developed areas with impervious HRU time series yields the post-development runoff conditions. In the fourth step, runoff time series from upland areas can be routed through BMPs for long-term simulation, and the runoff conditions are compared against the watershed predevelopment runoff conditions. The model implementation is an iterative process that helps identify appropriate BMP sizes to replicate the predevelopment runoff conditions.

5.4.4 Evaluation through the Continuous Simulation Coupled with Optimization Approach

The CS+O approach is also based on continuous simulation, with the added capability of achieving additional cost savings through spatial optimization. For an installation with varying underlying soils conditions, the specific placement and routing of flows to BMPs could have significantly different hydrologic benefits. An optimal configuration of BMP size and placement can be identified through the optimization process of matching predevelopment runoff conditions with minimum cost.

The implementation of the CS+O approach at an installation also takes four steps, of which the first three steps are the same as those in the CS approach. In the fourth step of the CS+O approach, a BMP site layout is created in the SUSTAIN model, and the optimizer is activated to search through possible BMP size configurations for the most cost-effective (i.e., minimum BMP volumes) solution.

5.4.5 Validation of the Model Selection Tool component

After the three detailed modeling approaches were evaluated at each of the two installations, the BMP sizing results were compared against each other, and the modeling approach with the smallest required BMP size (i.e., lowest cost) was identified. The identified modeling approach was then validated against MST predictions for the two installations to confirm that MST can accurately predict the most cost-effective modeling approaches at the two installations per the performance objectives listed in Table 3-1 (p. 13).

5.4.6 BMP implementation tools development

The final step of SMOT implementation is development of BMP implementation tools using the detailed modeling analysis results. This effort resulted in a BMP Sizing Tool, which guides base engineers to plan, assess, implement, track, and report development and BMP implementation activities. The BMP Sizing Tool is developed within an interactive Excel-based spreadsheet that uses user input to output a BMP sized to comply with applicable regulations (e.g., EISA). The acreage of proposed impervious area input by the user is used by the tool's algorithms to discern the expected level of runoff from the developed impervious area. The BMP size necessary to capture the required volume of stormwater is then calculated. The resulting BMP size serves as a planning-level assessment for compliance.

5.5 Field testing

Field testing of SMOT differs from processes involved in typical restoration projects. Instead of conducting site visits and monitoring activities, field testing of SMOT consists of the execution of MST, and a detailed SWMM and SUSTAIN modeling analysis to confirm its results. Validation of MST at both NAS Key West and APG included the creation of development scenarios that trigger stormwater capture requirements and represent the associated conversion of pervious area to impervious area within the models. Options for the conceptual siting of proposed BMPs were also developed to represent the mitigation of hydrologic effects of the proposed developed impervious area (e.g., flow volume). In this analysis, the modeling objective used to determine if the hydrologic effects of development have been mitigated was the AAFV running off the land surface. To represent the spectrum of potential development, three scenarios were generated to simulate an increase of 30%, 60%, and 90% of conceptually developable area for each installation. The resulting AAFV before and after development was simulated, with the requisite BMP size needed to return to predevelopment conditions identified.

The following subsections step through the details for developing the APG and NAS Key West models at the subcatchment and subwatershed scale. The process was completed at both scales to illustrate that the full-scale models and MST results apply broadly for catchments and bases of variable size.

5.5.1 APG subcatchment-scale modeling

Three development scenarios with variable proposed impervious cover for a small subcatchment on APG were created (Figure 5-4). Table 5-2 lists the developed area and underlying soils for the current condition, as well as the three development scenarios (30%, 60%, and 90%).

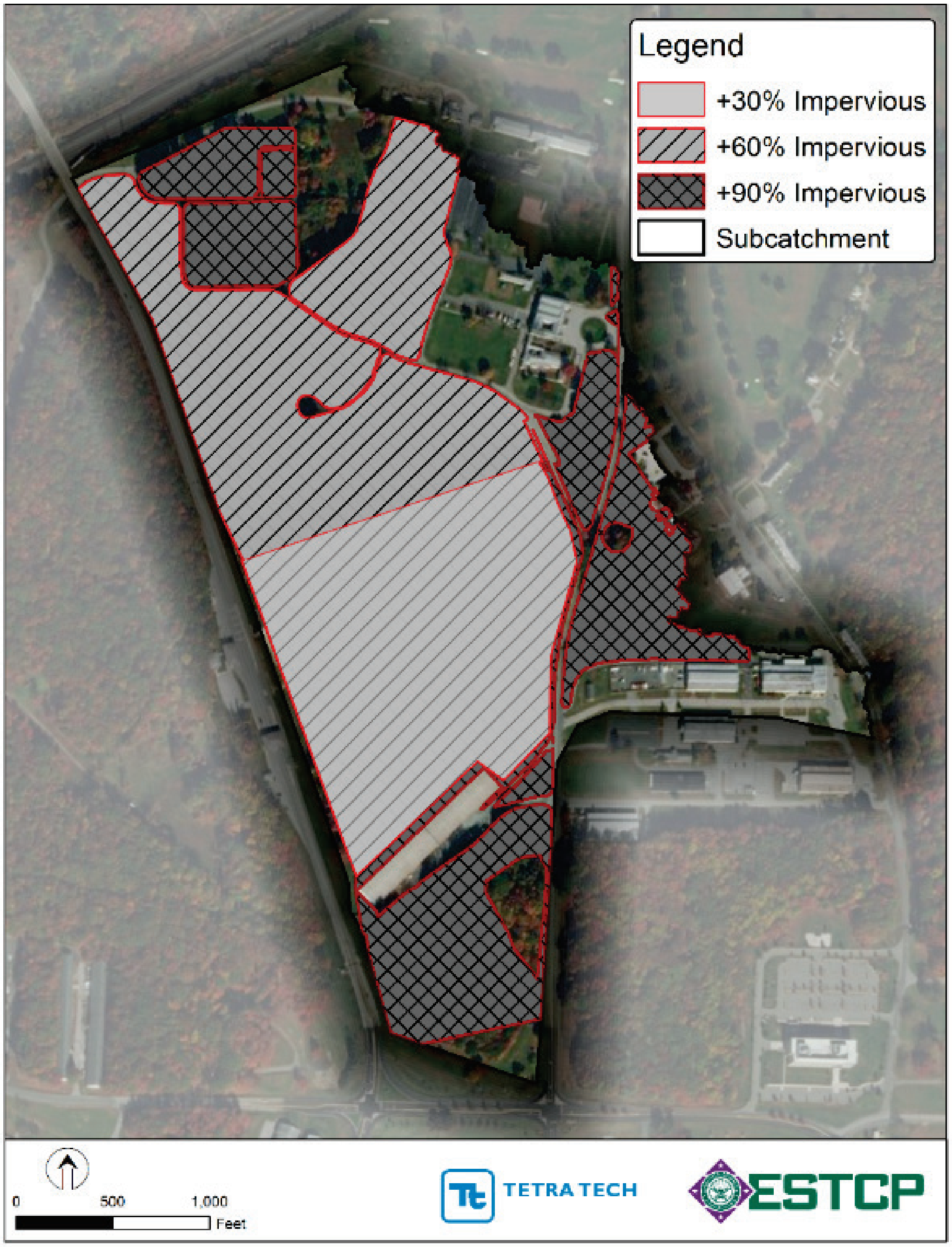
Figure 5-5 shows the distribution for each development scenario.

Table 5-2. Land cover for conceptual development scenarios at the subcatchment scale, APG.

HSG	Current Development (ac)	+30% Impervious Area (ac)	+60% Impervious Area (ac)	+90% Impervious Area (ac)
A	—	—	—	—
B	—	—	—	—
C	103.1	72.9	41.0	10.8
D	—	—	—	—
Impervious	15.6	15.6	15.6	15.6
Impervious (new)	0	30.2	62.1	92.3
Total	118.7	118.7	118.7	118.7

Figure 5-4. Selected subcatchment within the larger subwatershed on APG.

Figure 5-5. APG subcatchment development scenarios.



Two BMP siting scenarios were developed at APG to address the new impervious area: (1) one single (lumped) BMP proximal to the drainage outfall and (2) several (distributed) BMPs dispersed within the catchment. The spatial distribution of the different BMP scenarios was intended to validate that spatial optimization or placement does not generate significant savings when the underlying soils are homogenous. In both the lumped and distributed scenarios, the total upstream area draining to BMPs is identical, which is based on the assumption that the development and associated storm drain conveyance system would be designed such that it would drain to a downstream BMP. BMPs were sized using SWMM to determine the volume needed to restore AAFV to predevelopment conditions across all levels of proposed development. Provided that the BMP drainage area and volume are commensurate due to the homogeneous soils, BMP performance was the same wherever it was located. Figures 5-6 to 5-8 show each of the development scenarios (30%, 60%, 90% impervious) and each of the BMP techniques (lumped, distributed) in the subcatchment area.

The sizing results were compared to the output from the MST for each of the different development scenarios to validate whether the same modeling method was selected.

Figure 5-6. +30% impervious scenario with lumped (left) and distributed BMPs (right) at the subcatchment scale, APG.

Figure 5-7. +60% impervious scenario with lumped (left) and distributed BMPs (right) at the subcatchment scale, APG.

Figure 5-8. +90% impervious scenario with lumped (left) and distributed BMPs (right) at the subcatchment scale, APG.

5.5.2 APG subwatershed-scale modeling

The same strategy developed for the subcatchment-scale simulations (e.g., lumped and distributed BMPs) was applied at a broader scale, for the subwatershed models (Figure 5-9). Table 5-3 lists the acreage of development and underlying soil types for current conditions and the three development scenarios. Employing identical modeling and validation approaches for MST at various scales confirmed that the modeling framework is applicable not just at small scale applications, but base wide.

Table 5-3. Land cover for conceptual development scenarios at the subwatershed scale, APG.

HSG	Current Development (ac)	+30% Impervious area (ac)	+60% Impervious area (ac)	+90% Impervious area (ac)
A	—	—	—	—
B	2.1	2.1	2.1	2.1
C	976.7	683.7	390.7	97.7
D	130.1	130.1	130.1	130.1
Impervious	226.4	226.4	226.4	226.4
Impervious (new)	0	293.0	586.0	879.1
Total	1,333	1,333	1,333	1,333

Figures 5-10 to 5-12 show each of the development scenarios (30%, 60%, 90% impervious) and each of the BMP techniques (lumped, distributed) at the subwatershed scale at APG. The sizing results were compared to the output from the MST for each of the different development scenarios to validate whether the same modeling method was selected.

Figure 5-9. Subwatershed-scale modeling at APG.

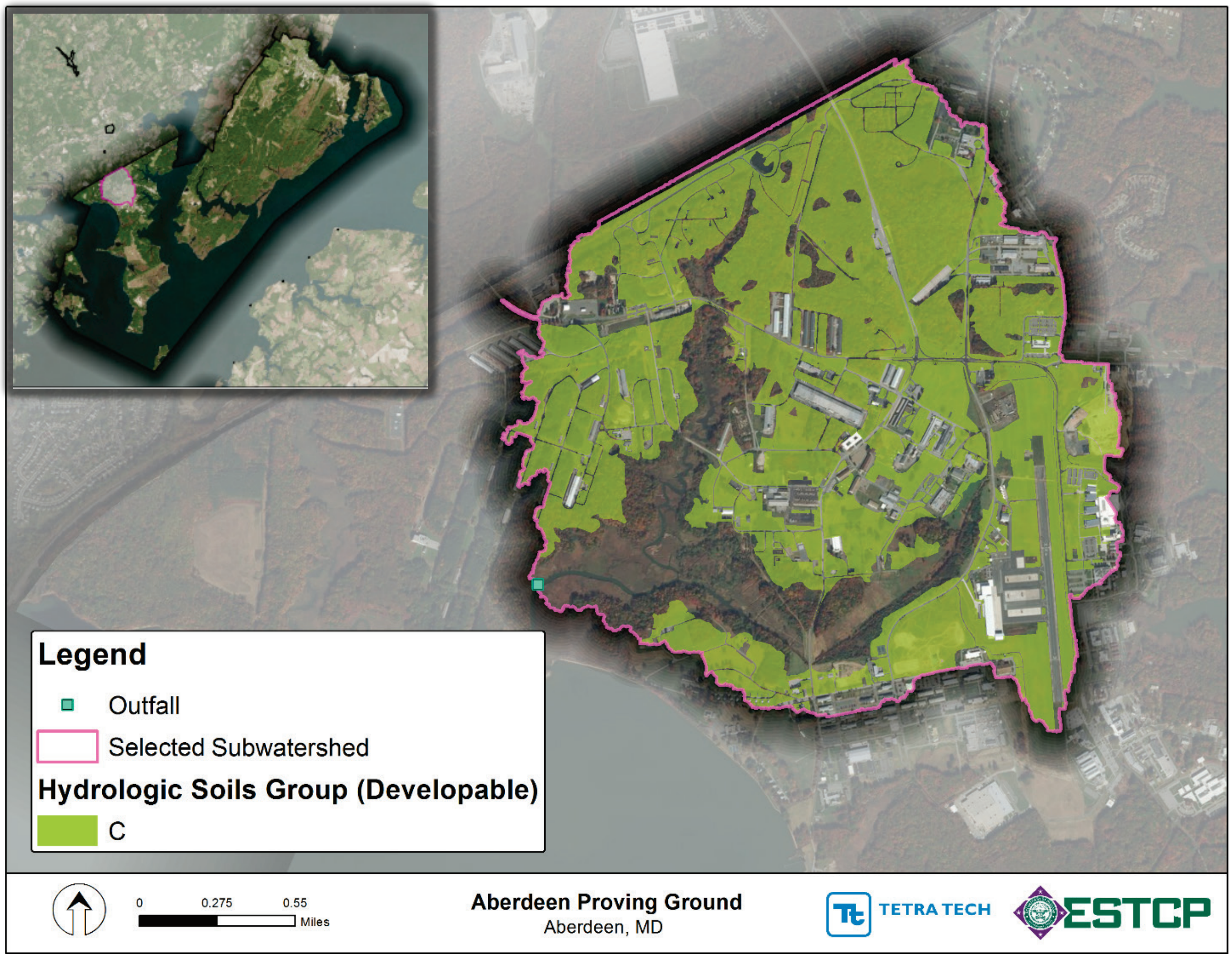


Figure 5-10. +30% impervious scenario with lumped (left) and distributed BMPs (right) at the subwatershed scale, APG.

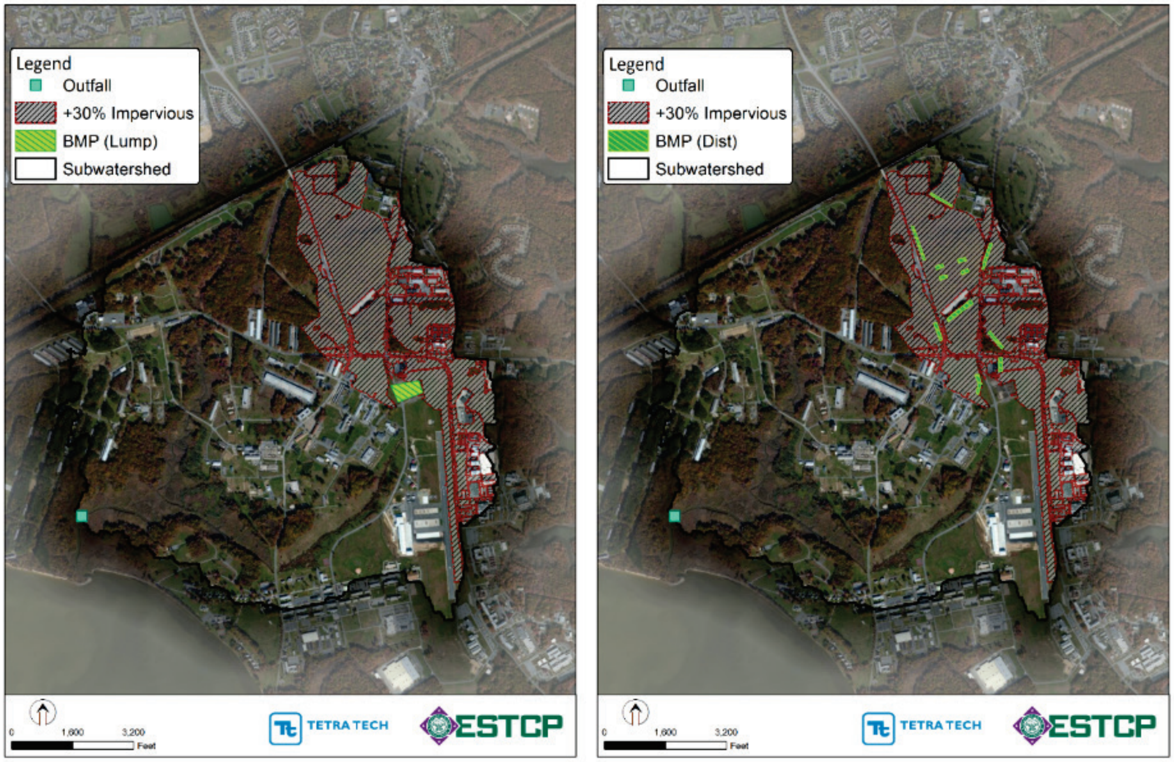


Figure 5-11. +60% impervious scenario with lumped (left) and distributed BMPs (right) at the subwatershed scale, APG.

Figure 5-12. +90% impervious scenario with lumped (left) and distributed BMPs (right) at the subwatershed scale, APG.

5.5.3 NAS Key West subcatchment-scale modeling

A SUSTAIN model was developed for a subcatchment area at NAS Key West. The underlying HSG composition at NAS Key West is heterogeneous, which was anticipated to provide cost saving opportunities through the use of spatial BMP optimization. The model formulation at NAS Key West was intended to validate this hypothesis.

In this subcatchment model, the area draining to both BMPs and the maximum available BMP footprint is identical (Figure 5-13). The only distinction between the two BMPs is the underlying soil type, where one is located over soils that are highly infiltrating (HSG A) and the other is located over soils that are hydraulically restrictive (HSG D). Two optimization models were executed to size the respective BMPs, where each BMP was sized for all available sizing combinations to demonstrate the range of capacity for matching the predevelopment AAFV. For NAS Key West, the same three development scenarios were executed with a proposed impervious cover of 30%, 60%, and 90% of the available developable land (Figure 5-14 and Table 5-4). Devising the subcatchment optimizations in this way enabled the performance and cost of each BMP particular to the underlying soil type to be assessed, allowing for the impact of heterogeneous soils on reducing AAFV after development to be quantified.

Figure 5-13. Selected subcatchment area and proposed BMPs on NAS Key West.

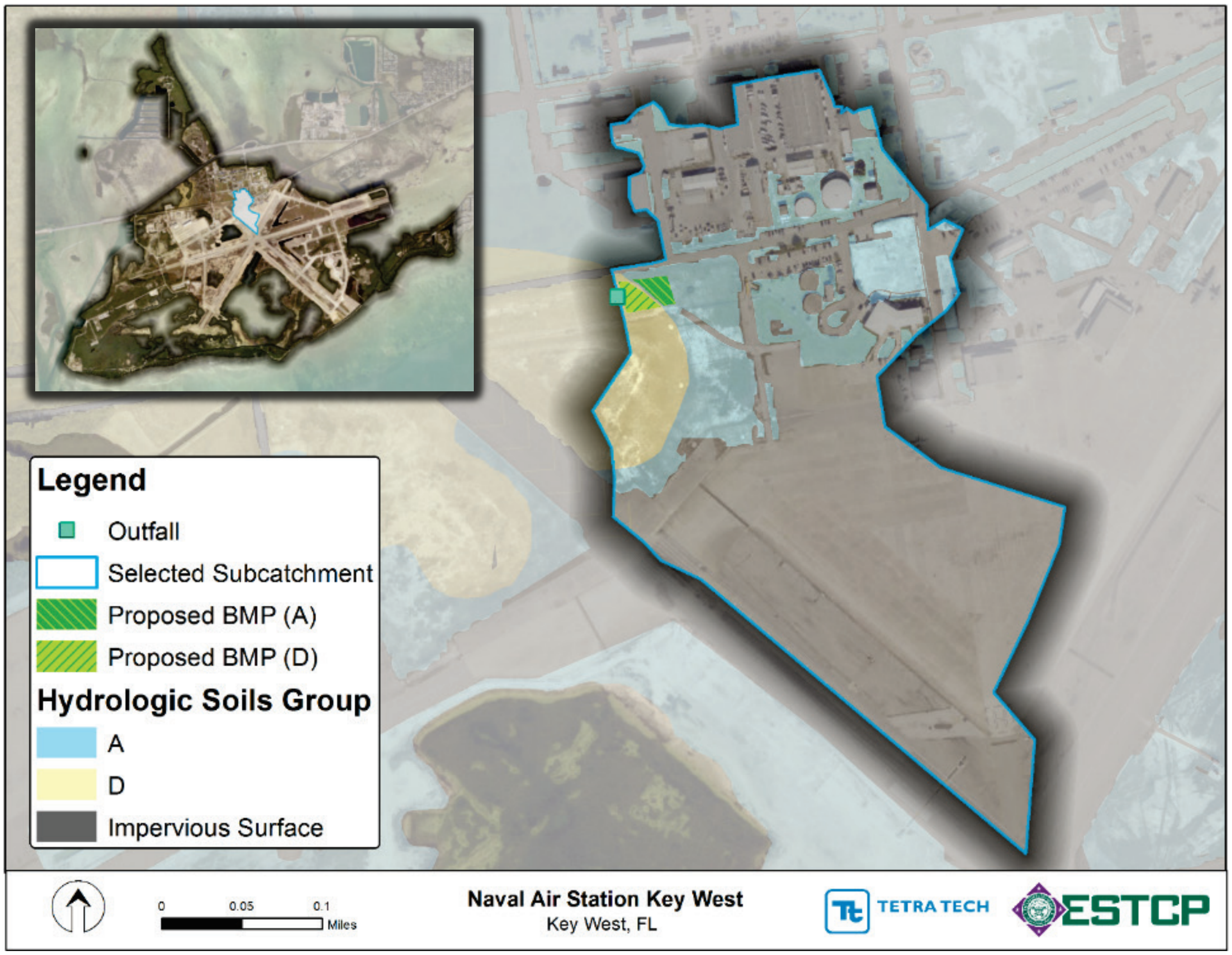
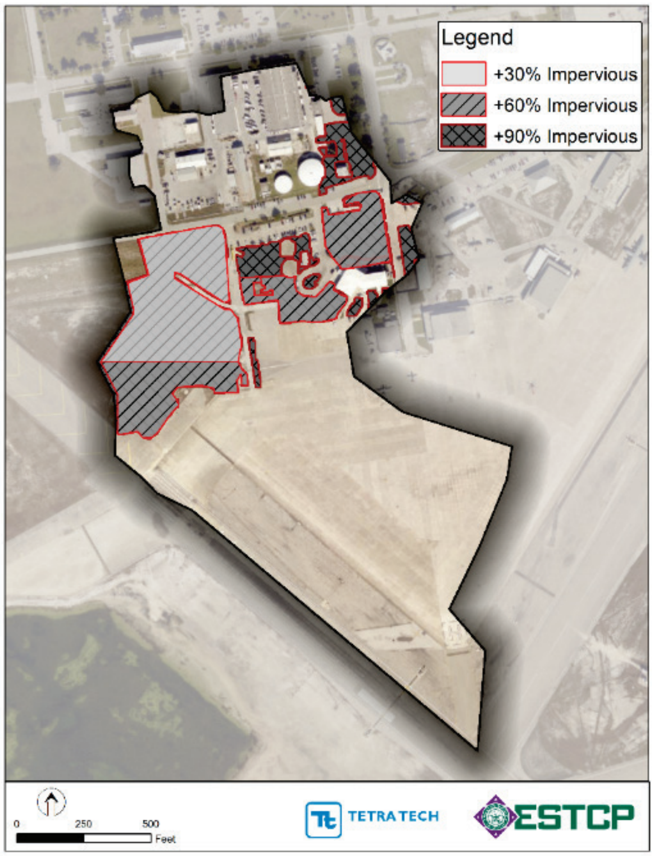


Table 5-4. Land Cover for Conceptual Development Scenarios at the Subwatershed Scale, NAS Key West.

HSG	Current Development (ac)	+30% Impervious area (ac)	+60% Impervious area (ac)	+90% Impervious area (ac)
A	8.84	6.83	4.83	2.82
B	—	—	—	—
C	—	—	—	—
D	2.66	2.04	1.42	0.80
Water	0.1	0.1	0.1	0.1
Impervious	36.41	36.41	36.41	36.41
Impervious (new)	0	2.63	5.25	7.88
Total	47.91	47.91	47.91	47.91

During each optimization routine, hundreds of BMP sizes were simulated to assess the corresponding cost-effectiveness for attenuating post-development runoff. The sizing results where then compared to the output from the MST for each of the different development scenarios to validate whether the same modeling method was selected.

Figure 5-14. Subcatchment Conceptual Development Scenarios, NAS Key West.



5.5.4 NAS Key West subwatershed-scale modeling

The same approach developed for the subcatchment-scale spatial optimization at NAS Key West was applied at the subwatershed scale to demonstrate the applicability of the modeling approach at different extents (Figure 5-15). For this model, 10 separate BMPs were sited across the different underlying soil types (five on HSG A and five on HSG D). Similar to the subcatchment-scale simulation, each of the potential BMP sizing combinations were run to develop a full suite of potential solutions for managing post-development runoff. Grouping BMPs by HSG allows for the direct comparison of their results to discern the performance of each set of BMPs. Table 5-5 lists the soil profiles of the 30%, 60%, and 90% added impervious scenarios.

Employing this approach at both the catchment and subcatchment scale confirmed that the chosen methodology is applicable not just at small scale applications, but base wide. Furthermore, it illustrated that the cost-effectiveness of the selected BMP combination is significantly greater due to spatial optimization. The sizing results were then compared to the output from the MST for each of the different development scenarios to validate whether the CS+O modeling method was selected.

Figure 5-15. Selected BMPs and their respective drainage areas at the subwatershed scale, NAS Key West.

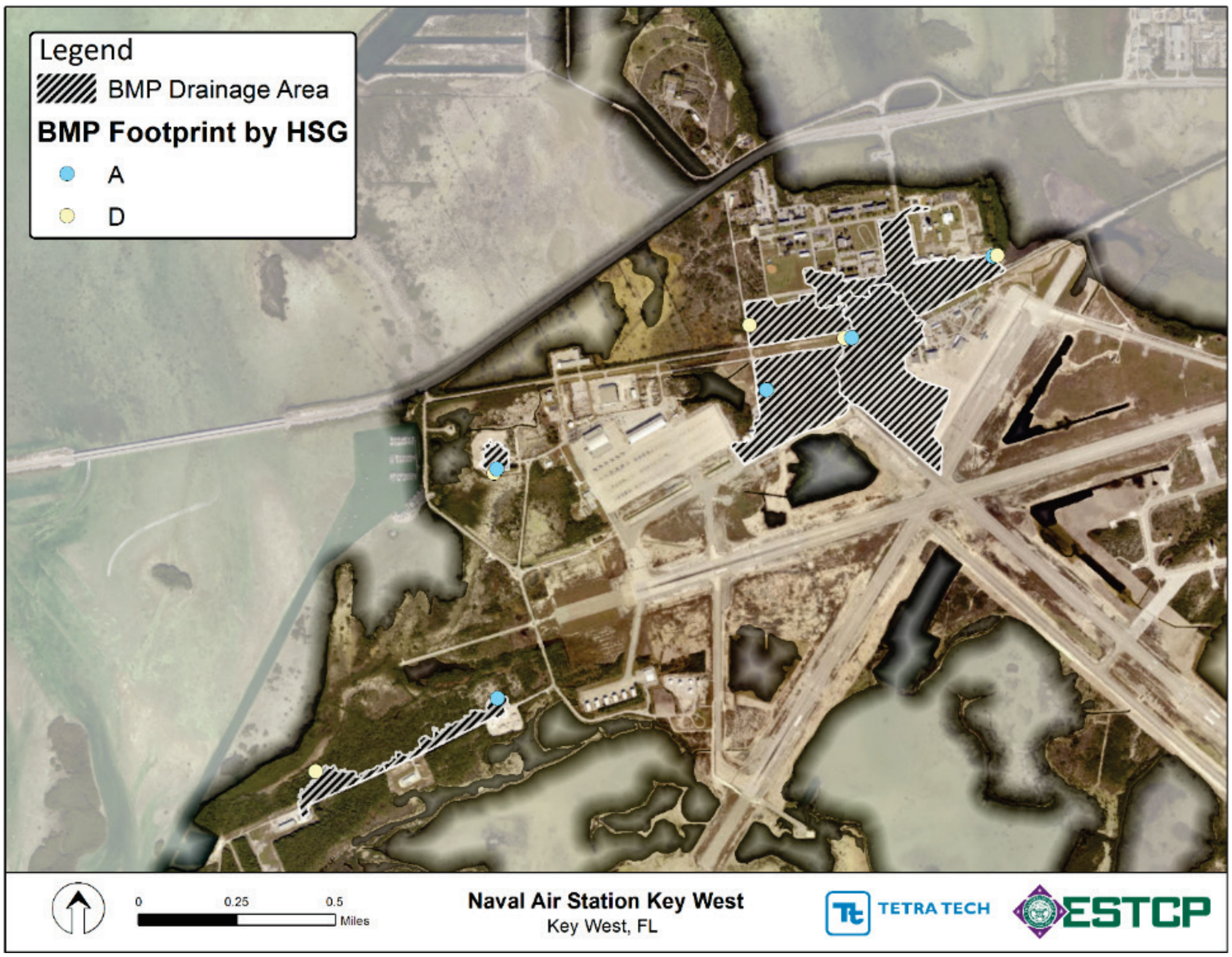


Table 5-5. Land Cover for Conceptual Development Scenarios at the Subwatershed Scale, NAS Key West.

HSG	Current Development (ac)	+30% Impervious area (ac)	+60% Impervious area (ac)	+90% Impervious area (ac)
A	656.2	646.7	635.9	625.1
B	—	—	—	—
C	—	—	—	—
D	964.5	958.8	951.6	944.4
Water	0.1	0.1	0.1	0.1
Impervious	441.6	441.6	441.6	441.6
Impervious (new)	—	15.3	33.2	51.2
Total	2,062	2,062	2,062	2,062

5.6 Sampling protocol

Unlike resource conservation projects that involve monitoring of pre- and post-restoration runoff conditions, SMOT demonstration does not involve sampling activities. Thus, no sampling plan was developed in this project.

5.7 Sampling results

Unlike resource conservation projects that involve monitoring of pre- and post-restoration runoff conditions, SMOT demonstration does not involve sampling activities. Thus, no sampling results were presented for this project. All results are discussed in detail in chapter 3, “Performance Objectives.”

6 Performance Assessment

Both APG and NAS Key West were evaluated by MST, and by using a detailed model approach (either continuous simulation coupled with or without optimization) as part of this demonstration. The results of the models with respect to each of the performance objectives detailed in chapter 3 of this report are presented in this section.

6.1 MST model approach selection validation (Performance Objective 1)

The quantitative performance objectives for the selected installations involved validating results of the MST with that of a detailed modeling analysis. The success criteria for this metric, as listed and defined in Table 3-1 (p. 13), focus on quantifying the difference in BMP size (a proxy for BMP cost) for each modeling approach (DS, CS, CS+O) to meet applicable regulations (e.g., EISA and TMDL). Each installation was modeled under a variety of development conditions and BMP implementation configurations to provide numerous scenarios where results could be compared to MST. The following sections present the results of the detailed modeling approaches at the catchment and watershed scales at both of the installations with regards to this performance objective.

6.1.1 APG

APG was selected as a site with a largely homogenous soil distribution and TMDL requirements, which resulted in the recommendation of the CS approach by MST. Results from the detailed modeling analysis show that the BMP size necessary to meet the predevelopment AAFV is the same regardless of location for all spatial extents (subcatchment and subwatershed scale) and development scenarios (development of 30%, 60%, and 90% of developable pervious area).

6.1.1.1 Subcatchment-scale results

Figures 6-1 to 6-3 show the AAFV for the subcatchment-scale models at each development level. The AAFV for the current condition is shown as a horizontal red line, and the AAFV after development and after BMP implementation (lumped and distributed) are represented as bars on the graph. In each simulation, the sum of the lumped and distributed BMP volume and drainage areas were identical, indicating that they are equally capable of restoring hydrologic conditions when sized correctly. Table 6-1 lists the corresponding BMP size for each scenario at the subcatchment scale.

Figure 6-1. AAFV for 30% development at the subcatchment scale, APG.

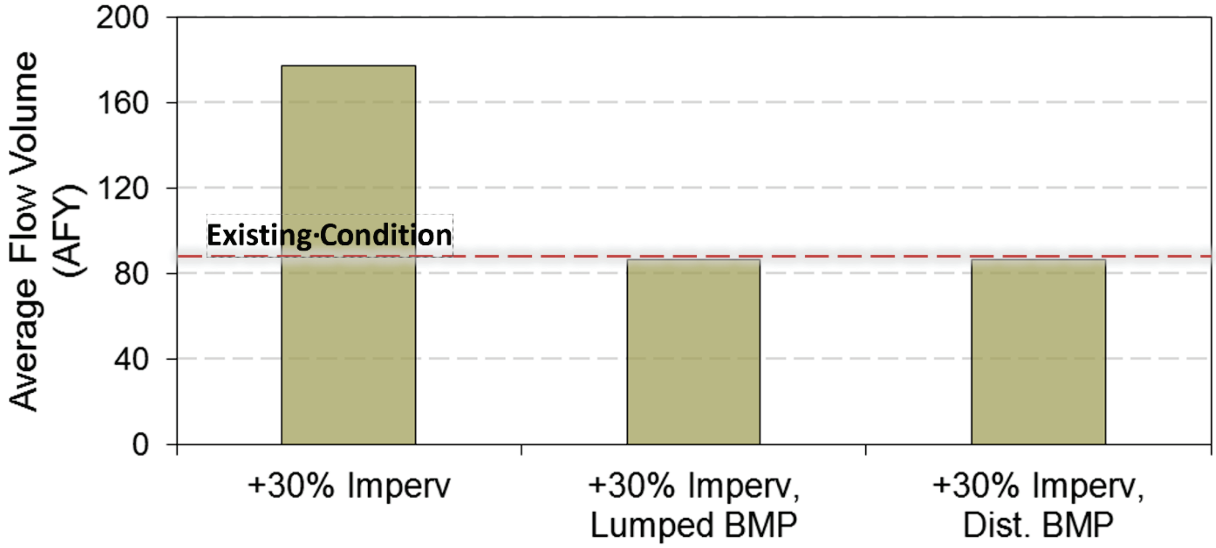


Figure 6-2. AAFV for 60% development at the subcatchment scale, APG.

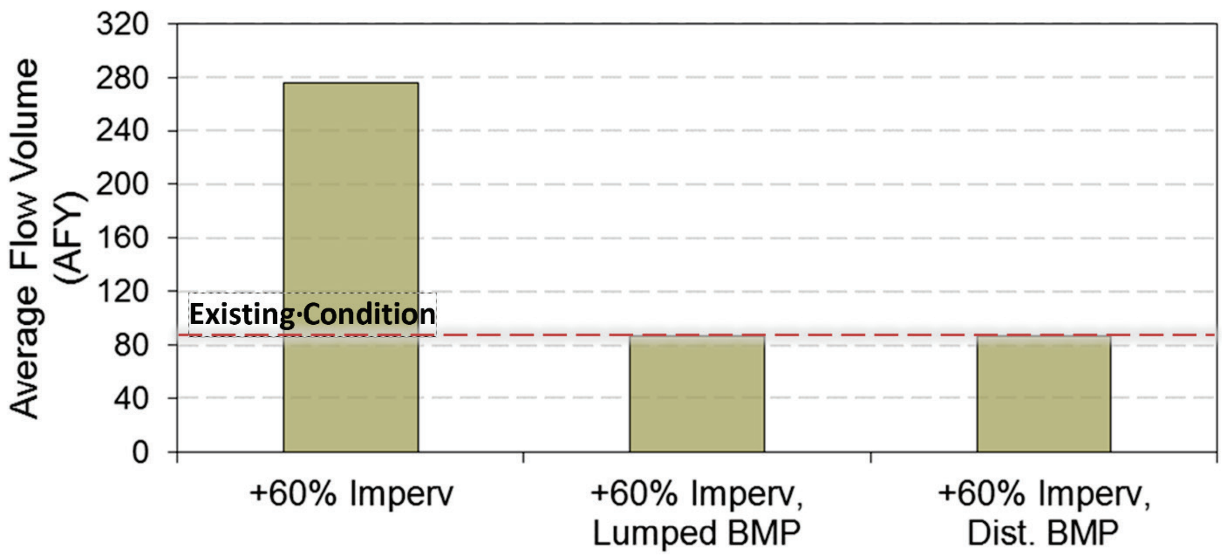


Figure 6-3. AAFV for 90% development at the subcatchment scale, APG.

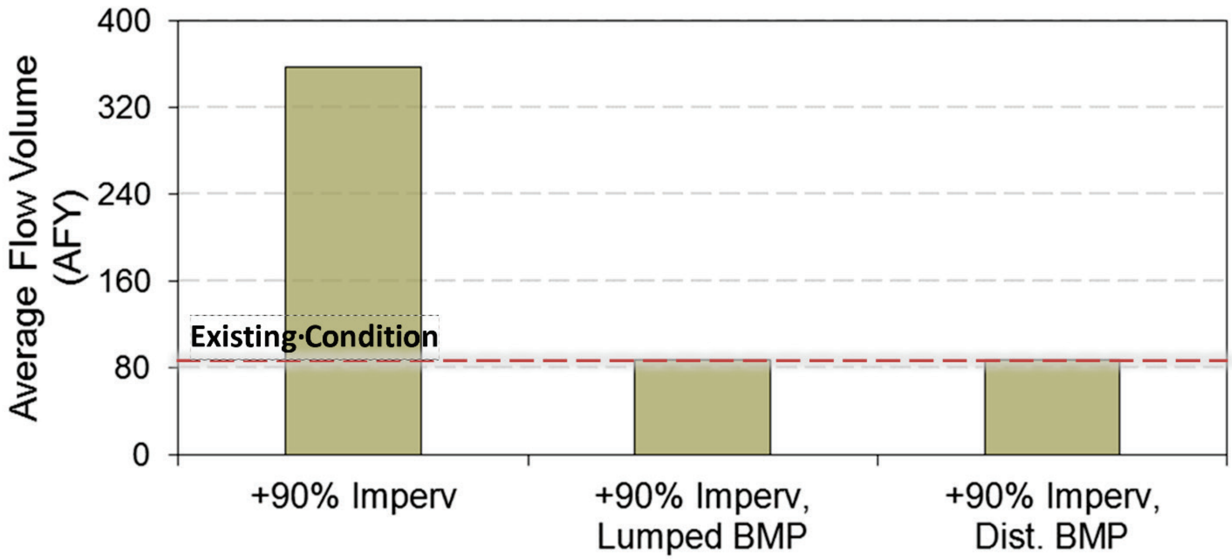


Table 6-1. BMP Results for the Development Scenarios at the Subcatchment Scale, APG.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Size (ac)	Design Storm	2.48	4.19	5.81
	Lumped	0.97	2.93	4.41
	Distributed	0.97	2.93	4.41

For all of the subcatchment development scenarios at APG, the BMP volume needed to reduce the AAFV to predevelopment conditions is identical whether the BMP is lumped or distributed. These results indicate that the specific placement and distribution of BMPs do not generate a significant cost savings in a homogenous soil setting. This analysis confirms that the success criteria has been met for the subcatchment-scale scenarios: (1) BMP sizes resulting from the CS and CS+O approaches are within 10% of each other, and (2) CS is at least 10% smaller than the DS approach.

6.1.1.2 Subwatershed-scale results

Similar results were observed for the subwatershed-scale models (Figure 5-9) across all three development scenarios (30%, 60%, and 90% development). The goal of this assessment was to demonstrate that the results of the subcatchment-scale model would also translate to a larger scale. Figures 6-4 to 6-6 show the results for the subwatershed-scale modeling approach. Table 6-2 lists the corresponding BMP sizes for the subwatershed models.

Figure 6-4. AAFV for 30% development at the subwatershed scale, APG.

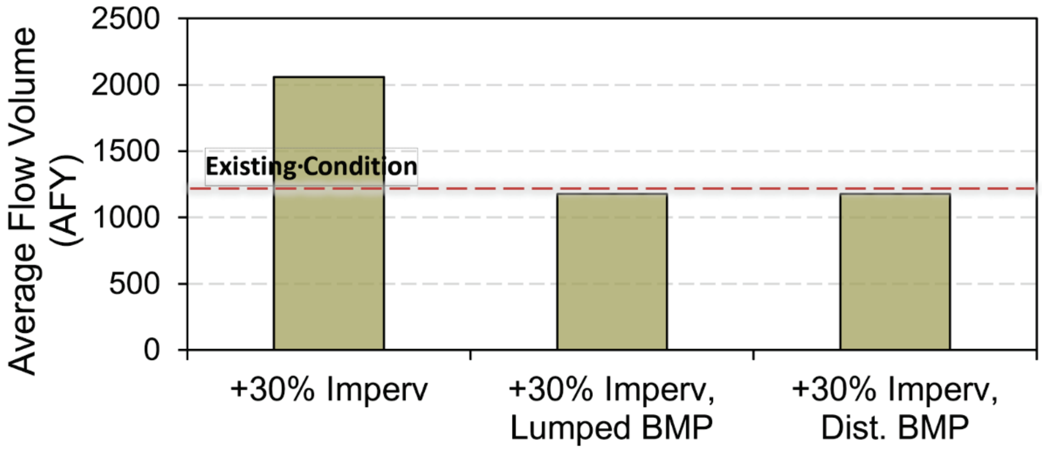


Figure 6-5. AAFV for 60% development at the subwatershed scale, APG.

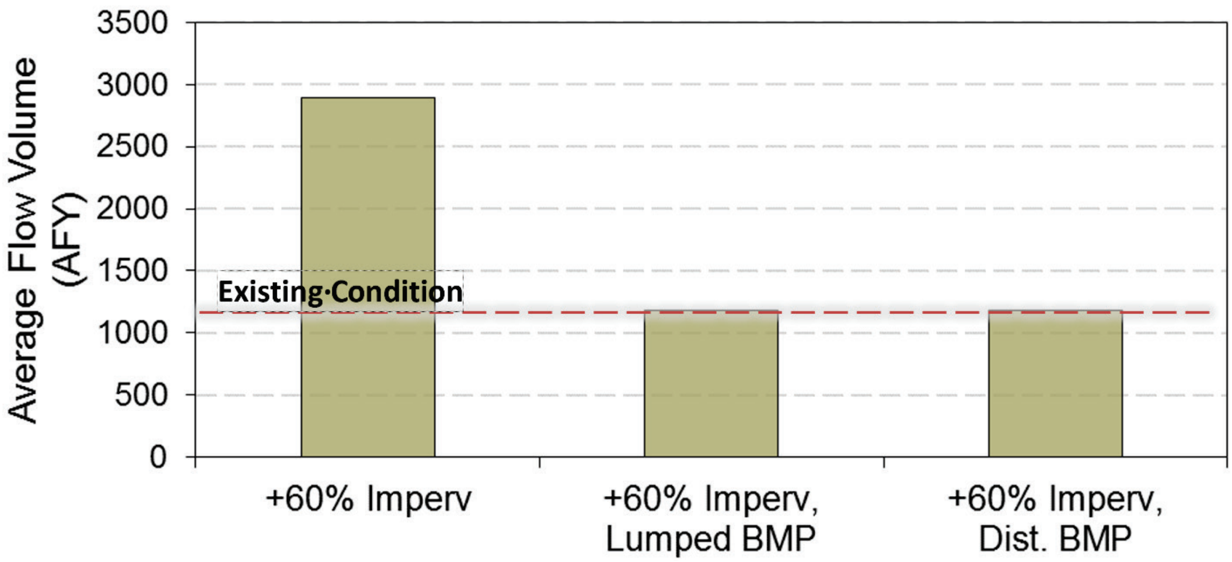


Figure 6-6. AAFV for 90% development at the subwatershed scale, APG

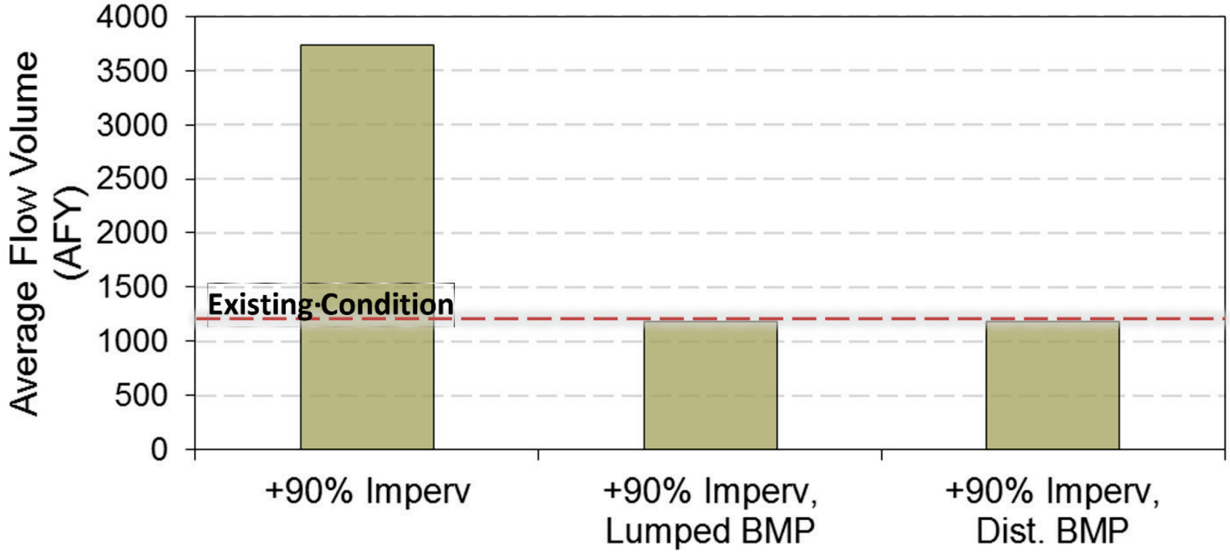


Table 6-2. BMP results for the development scenarios at the subwatershed scale, APG.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Area (ac)	Design Storm	35.8	55.9	76.1
	Lumped	7.9	19.7	34.4
	Distributed	7.9	19.7	34.4

The data shown in Figures 6-4 to 6-6 and listed in Table 6-2 indicate that the results of the subwatershed-scale models are consistent with the results of the subcatchment-scale models. Regardless of spatial scale, BMP sizes from the CS and CS+O simulations were within 10% of each other and BMP sizes for the DS approach are greater than the CS approach by 10%. These results confirm that optimization does not yield significant savings for APG and that the recommendations from MST and detailed modeling efforts are consistent at APG, satisfying the overarching performance objective (Table 6-3).

Table 6-3. Results of the MST and Detailed Modeling Analysis for APG.

Development Scenario	APG (MST)	Detailed Modeling Validation	
		Subcatchment	Subwatershed
30%	CS	CS	CS
60%	CS	CS	CS
90%	CS	CS	CS

6.1.2 NAS Key West

NAS Key West was selected as a site with high cost savings potential when the spatial optimization method was applied due to the largely heterogeneous soil distribution. MST confirmed this hypothesis by identifying the CS+O approach as generating a significant cost savings. Results from the detailed modeling analyses below include both the subcatchment and sub-watershed scale at all three development levels (30%, 60%, and 90% of developable pervious area). In all scenarios, the detailed models indicate that spatial optimization generates at least a 10% cost savings when the BMPs area is sized to meet the predevelopment AAFV, indicating that the CS+O approach is beneficial. BMP costs shown in Figures 6-7 to 6-9 were determined from completing a comprehensive regional analysis to determine planning-level region specific constructions costs (see section 7.1.2).

6.1.2.1 Subcatchment-scale results

Figures 6-7 to 6-9 show the results for the subcatchment-scale modeling approach. In each figure, the AAFV for the current condition is shown as a horizontal red line. The AAFV resulting from different sizes of BMPs (blue dots sited in HSG A and yellow dots sited on HSG D) are indicate how the cost and corresponding size vary. The variable costs for achieving the pre-development AAFV between the two BMPs can be attributed to the greater infiltrative capacity of the BMP on HSG A, which is able to percolate stormwater at a greater rate than the BMP on HSG D. These results indicate that strategically identifying and siting BMPs over HSG A soils at NAS Key West is beneficial for achieving regulatory standards. Table 6-4 lists the corresponding BMP sizes for each of these scenarios.

Figure 6-7. AAFV for 30% development at the subcatchment scale, NAS Key West.

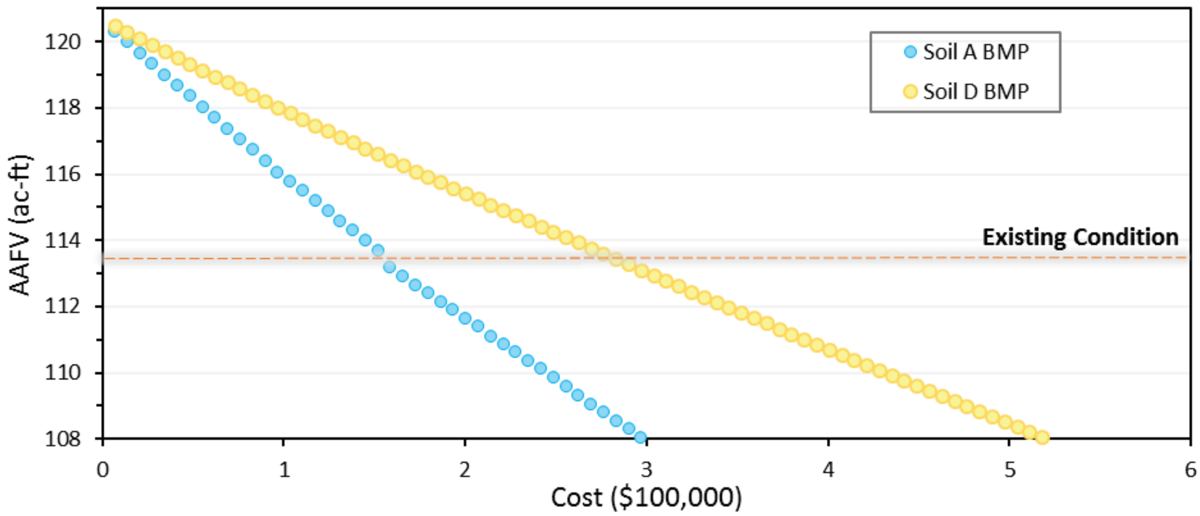


Figure 6-8. AAFV for 60% development at the subcatchment scale, NAS Key West.

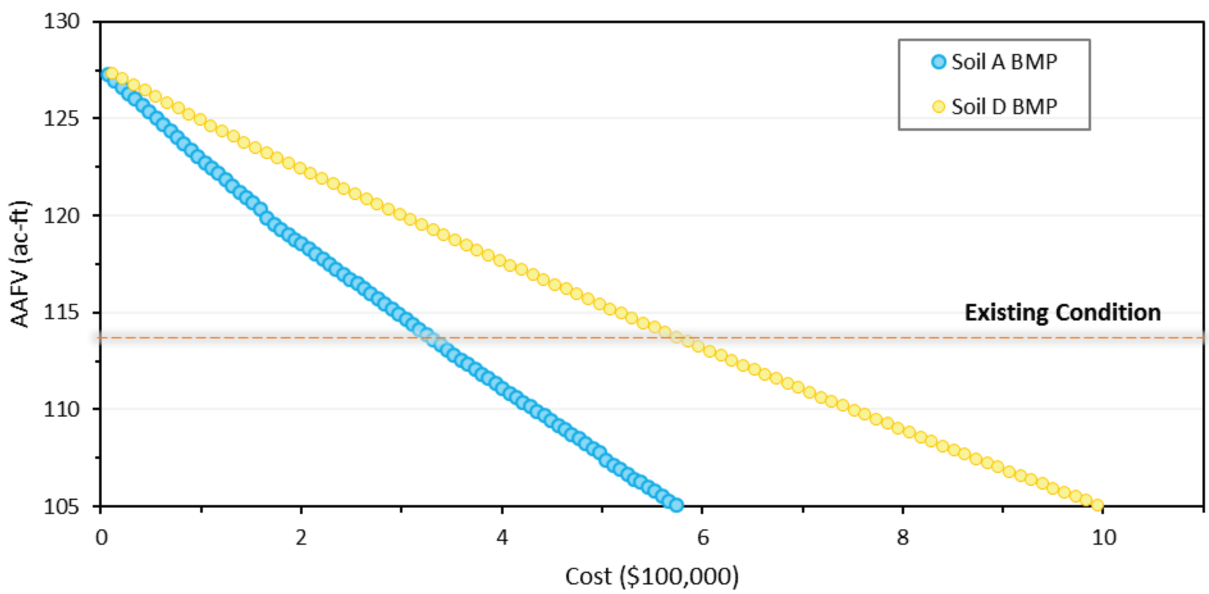


Figure 6-9. AAFV for 90% development at the subcatchment scale, NAS Key West.

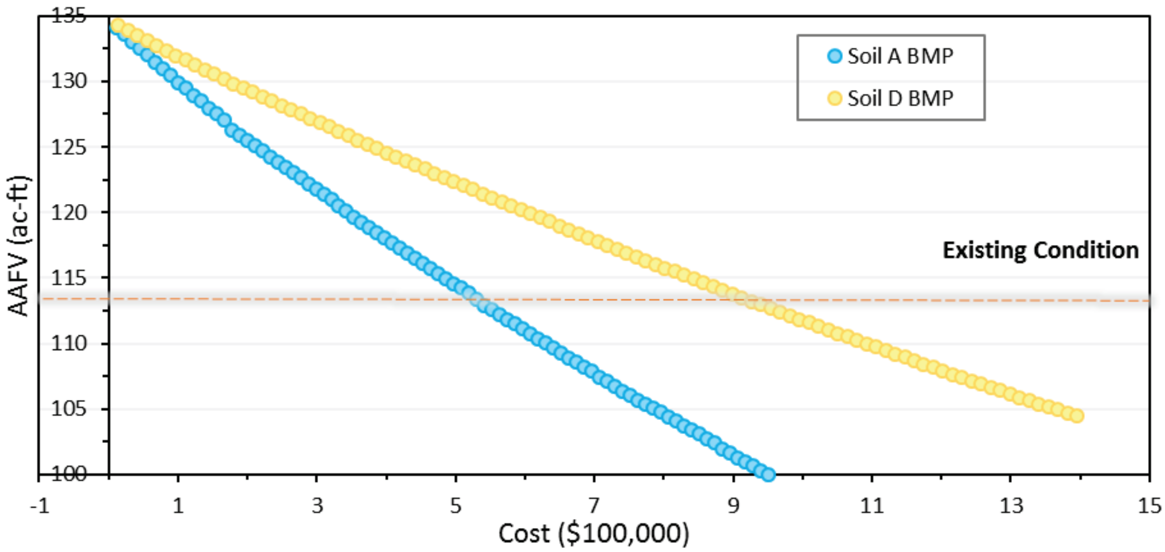


Table 6-4. BMP Results for the Development Scenario at the Subcatchment Scale, NAS Key West.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Area (ac)	Design Storm	2.74	2.93	3.10
	HSG A	0.08	0.17	0.26
	HSG D	0.14	0.29	0.45

These results show that the BMP volume needed to reduce the AAFV to predevelopment conditions is greater for the BMP sited on HSG D than for HSG A, indicating that an optimization is beneficial at the subcatchment scale. Additionally, the spatially optimized BMP volume required is significantly less than what is needed to satisfy the design storm method.

6.1.2.2 Subwatershed-scale results

A similar approach was used to size BMPs across a subwatershed-scale area within Key West, with the only difference being that multiple (10) BMPs were sited throughout. Similar to the subcatchment-scale model, half of the simulated BMPs (five) were sited on HSG A and the other half (five) on HSG D to meet the predevelopment AAFV at each development level (30, 60 and 90%). Figures 6-10 to 6-12 show the results for the three subwatershed-scale development scenarios. Table 6-5 lists the corresponding BMP sizes for each of these scenarios.

Figure 6-10. AAFV for 30% development at the subwatershed scale, NAS Key West.

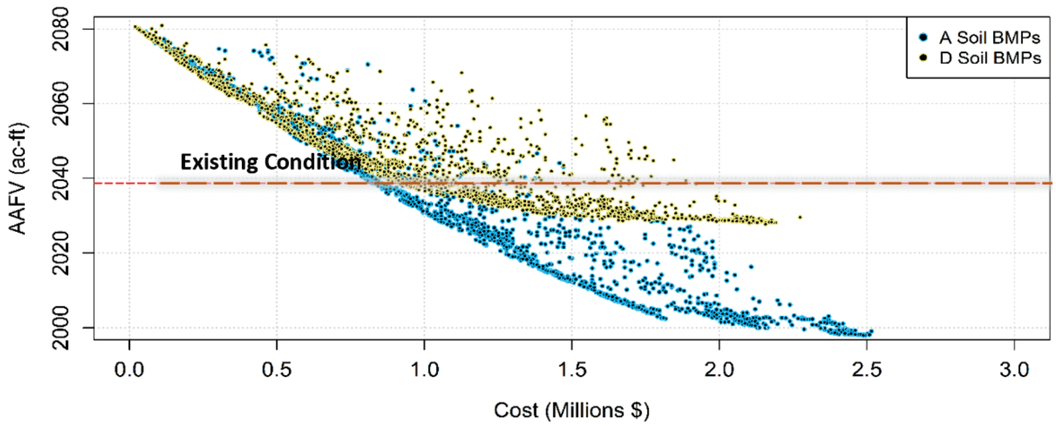


Figure 6-11. AAFV for 60% development at the subwatershed scale, NAS Key West.

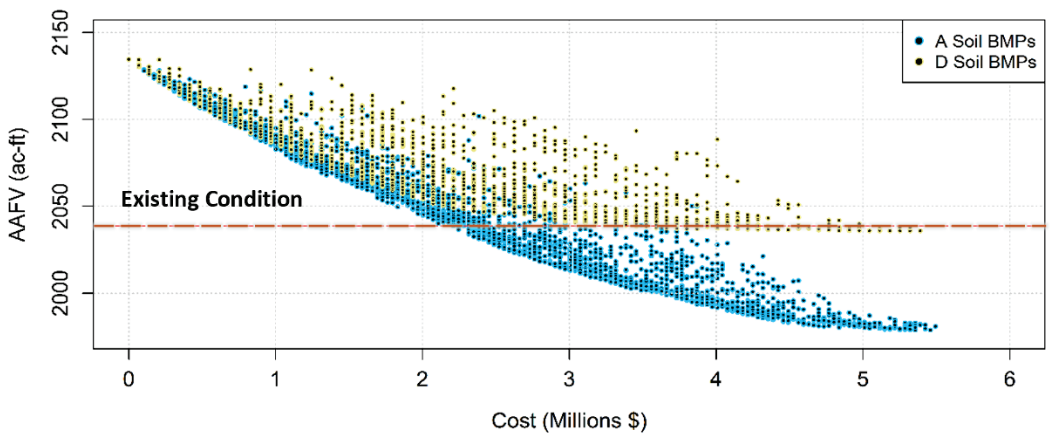


Figure 6-12. AAFV for 90% development at the subwatershed scale, NAS Key West.

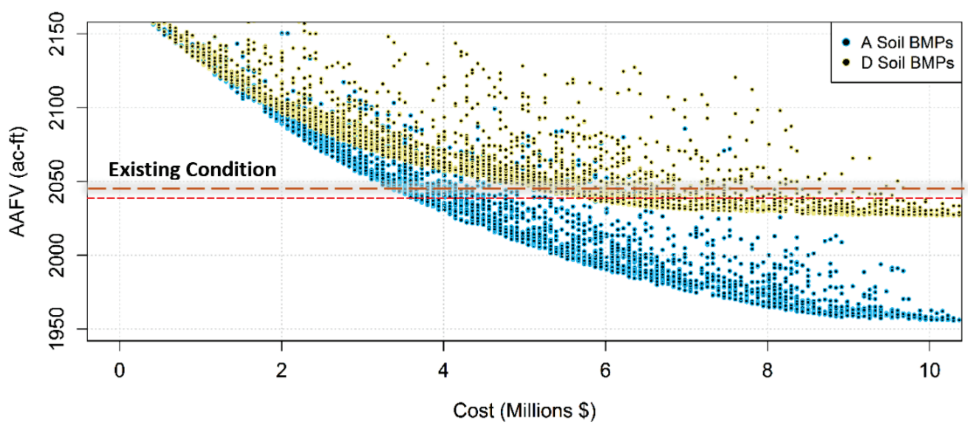


Table 6-5. BMP results for the development scenario at the subwatershed scale, NAS Key West.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Area (ac)	Design Storm	31.6	32.89	34.13
	HSG A	0.41	1.14	1.83
	HSG D	0.46	1.65	2.89

Results in Figures 6-10 to 6-12 and Table 6-5 illustrate two main points: (1) there exists a tremendous range of costs and performance associated with sizing and siting 10 BMPs and (2) the grouping of BMPs on HSG A outperform those on HSG D, especially as development area increases. For each simulation, there are over 10,000 unique combinations possible, meaning 10,000 different BMP sizing and siting opportunities in the plots. With this many potential solutions, the benefit for an installation to use a spatial optimization method only increases.

Also illustrated in Figures 6-10 to 6-12 is that the results from the subwatershed-scale model are consistent with those of the subcatchment scale confirming that the CS+O recommendation by MST is appropriate and applicable at all scales (Table 6-6).

Table 6-6. Results of the MST and Detailed Modeling Analysis for NAS Key West.

Development Scenario	APG (MST)	Detailed Modeling Validation	
		Subcatchment	Subwatershed
30%	CS+O	CS+O	CS+O
60%	CS+O	CS+O	CS+O
90%	CS+O	CS+O	CS+O

6.2 Data availability (Performance Objective 2)

A number of datasets were required to perform the range of model simulations executed for this demonstration. For each installation, the data were either provided by the installation or could be obtained from a publicly available source (Table 6-7). Receipt, organization, and processing of the data allowed for the successful execution of both the MST and detailed modeling analyses, which meets the performance objective for both installations.

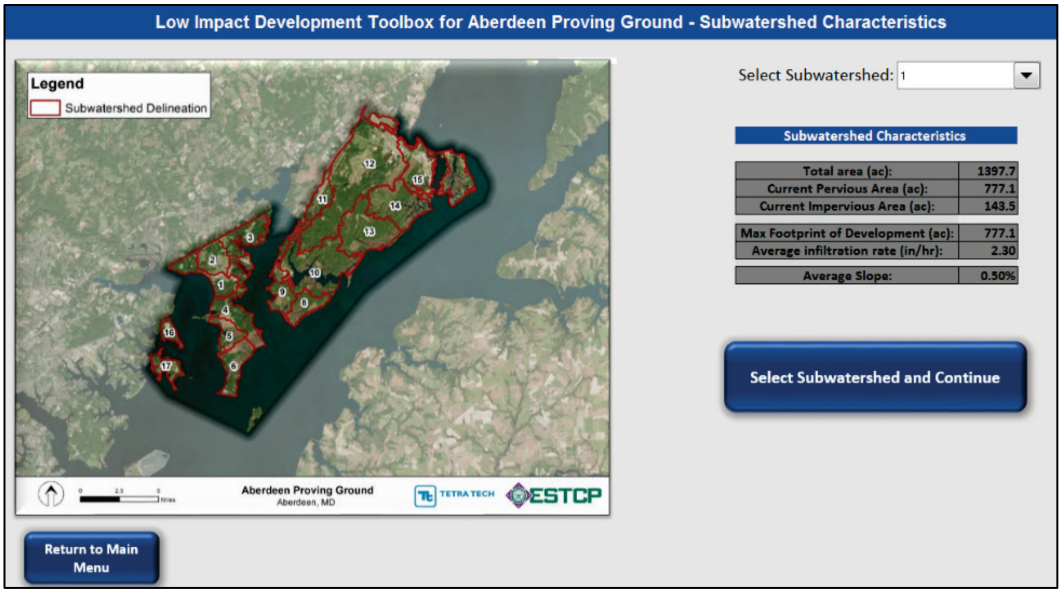
Table 6-7. Data required for model simulation analysis.

Geospatial Data	APG	NAS Key West	Source
HSG representation	✓	✓	NRCS (2016)
Storm Drain Network	✓	✓	Provided
Land Use	✓	✓	Provided
Existing BMPs	✓	✓	Provided
Impervious Area	✓	✓	Provided
DEM	✓	✓	Provided or USGS (2016)
Developable Pervious	✓	✓	Provided or NOAA (2017)
Observed Data			
Continuous Rainfall Gauge Timeseries (10+ years)	✓	✓	Provided or NCDC (2017)

6.3 BMP implementation tool

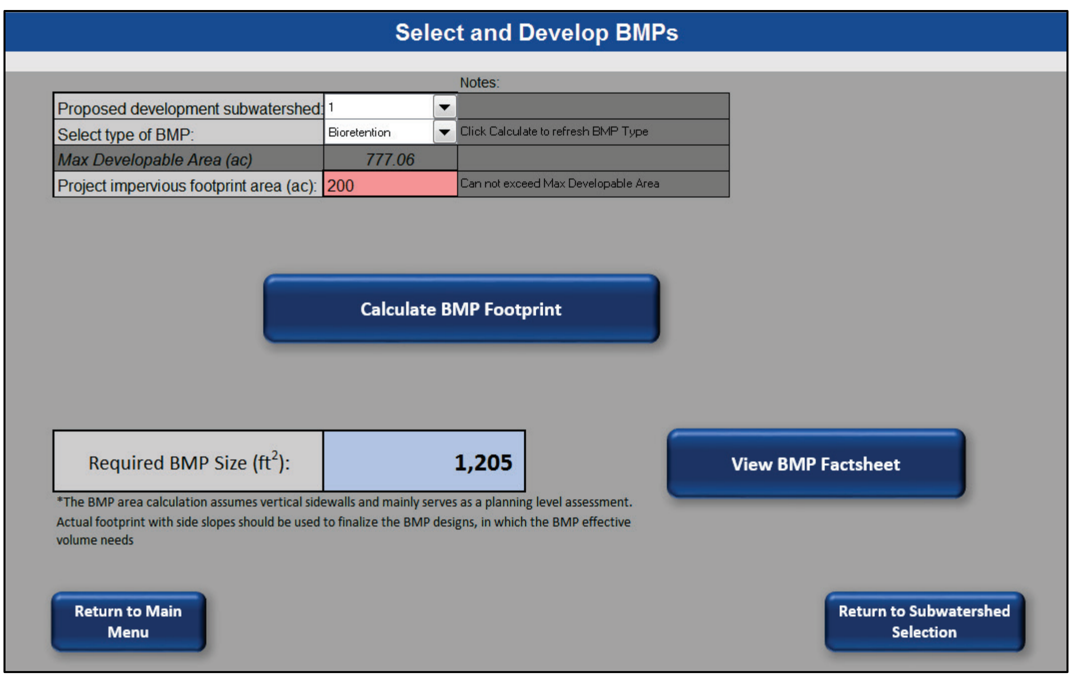
The final step of SMOT implementation at APG and NAS Key West was the development of respective BMP implementation tools using the detailed modeling analysis results. The BMP Sizing Tool created for each of the installations is designed to offer the user planning-level BMP sizes and configurations to meet the applicable regulations within an intuitive Excel-based interface. To complete this, the user opens the Sizing Tool and is directed to select the subwatershed in which the proposed development takes place within the installation. For each subwatershed, the critical site characteristics (e.g., HSG composition, max developable pervious area, etc.) auto populates with preloaded data (Figure 6-13).

Figure 6-13. Interface for the BMP Sizing Tool for APG showing the subwatershed selection.



Next, the user inputs the proposed impervious area that was developed in the selected subwatershed, which enables the embedded BMP Sizing Tool to identify the post-development AAFV and the subsequent BMP size necessary to capture the increase in runoff (Figure 6-14).

Figure 6-14. Interface for the BMP Sizing Tool for APG showing the bmp sizing results.



The tool also includes a sample cross-section and assumptions for calculation of surface BMP area. The user can leverage BMP volume necessary to customize BMP dimensions (e.g., depth, freeboard, sidewalls, etc.) to identify a site-specific configuration.

6.4 Ease of use

Currently (for those with a.mil address), SMOT is housed at https://nzp.erdc.dren.mil. Starting November 01, 2018 (for those with a.mil address), SMOT will be housed at: https://smpl.erdc.dren.milNZP. For public, SMOT can be provided in the original spreadsheet via email when requested. Tutorial videos have been developed along with the SMOT User Manual to help individuals with the data requirements for rainfall time series and soils. In addition, general walk-thru videos for both the Net Zero Planner (NZP) tool and spreadsheet are provided. Videos are available at:

- SMOT NZP https://youtu.be/ze_GT_bSDmE
- SMOT Spreadsheet Tutorial https://youtu.be/KoYqABCxOIg
- NOAA Rainfall Timeseries Tutorial https://youtu.be/rjbLaAJSImE
- Soil Survey Geographic (SSURGO) Database tutorial https://youtu.be/Kogx_vfacsI

SMOT was provided to a range of expertise levels, from undergraduate Agricultural Engineering students to graduate students in Civil Engineering and Urban Planning; to U.S. Army Corps of Engineers (USACE) District Hydrologists; to installation stormwater managers; to Urban Planners. Initial testing began with a small group at the Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) who were responsible for programing the tool into NZP. The team consisted of one Urban Planner, three Civil Engineers-Hydrologists, an Agricultural Engineer, and an Agronomist. Based on results from this core group, the User Manual was refined. Later, the tool and updated User Manual were provided to approximately 10 District Engineers who are responsible for documentation of LID and EISA 438 compliance. We also provided SMOT, on request, to two naval base Engineers, and 10 independent consulting firms (primarily Urban Planners). To stress test SMOT, we were given the opportunity to have the tool used in a senior design class, 20 seniors and juniors, at the University of Illinois. The senior design class used SMOT on a series of projects assessing stormwater requirements. In general, the feedback received from individuals with more than 5 years of experience was more positive than that from those with more limited experience.

We analyzed the data collected for Performance Objective 3 based on the graded surveys administered to the users. Responses were limited with a 31% response rate, 13 out of 42, seven of whom were students. Total average was 3.53 (Table 6-8).

Table 6-8. Average scores of survey questions.

Question	Average Score
Overall design of Model Selection Toolbox is user friendly	3.69
User manual is clear, concise, and easy to follow	3.62
Resources and expertise required to run Model Selection Toolbox is reasonable	3.54
Data requirements for the tool are readily available	3.62
Data input to run Model Selection Toolbox is easily accomplished	3.54
Data input to run Model Selection Toolbox is appropriate	4.23
Model Selection Toolbox consistently chooses mom cost-effective modeling approach for a variety of site conditions	3.77
Total BMP footprint are substantially reduced	3.92
Toolbox output interoperated is easily -understood and	3.23
Toolbox output is easily adjusted for installation needs	2.38
Time spent in analysis is less than other currently used model selection tools	1.62
Cost benefit of the Model Selection Toolbox is worth effort	3.62
Final results are acceptable	3.08

6.4.1 Resources and expertise

Engineers and Urban Planners with 1 to 5 years of experience in stormwater management were able to immediately start using the model in less than 4 hours for a small drainage area or watershed. Collection and preparation of datasets did take a bit longer than the 3 days we originally estimated for the first area of interest setup. The primary complaint was on developing the required datasets for rainfall time series and how to identify the gauges, etc. (survey questions 4 and 5). Based on initial feedback, we developed a series of web-based tutorials that can be downloaded from “YouTube.”

6.4.2 Time needed to run SMOT

Running time for SMOT is considerably less than the estimated 1 minute for sub drainage sheds small watersheds and drainage areas. When the area of interest was in excess of 10,000 acres, it obviously took longer than 1 minute. This was discovered when the undergraduate senior design students were inappropriately using the tool for an entire installation of 33,000 acres and had not read the User Manual. Once we pointed out the issue and they properly identified the sub watershed, the tool performed as expected. The BMP Sizing Tool did take longer than 2 minutes, depending on the size of the area of interest and computing power. It completely timed out for areas exceeding 1000 acres.

6.4.3 Degree of expertise needed to interpret results

We found that more experienced individuals who used the tool were able to quickly understand the recommendations and the processes behind the recommendations, were able to interpret results regarding the recommended BMP size, and were able to identify the most cost-effective option immediately. Minimal discussion was needed to walk anyone using the tools through the outputs. This was anticipated due to the level of expertise and background in stormwater management of the individuals who used the tool.

7 Cost Assessment

Validation of SMOT is different from validations of demonstrations of conventional resource conservation projects in that SMOT validation involves stormwater modeling analyses. Activities that are common to conventional restoration activities, such as treatability studies, physical construction of restoration projects, waste disposal, regular project operation and maintenance, and long-term monitoring activities, are not applicable to this exercise.

7.1 Cost model

Due to the nature of this demonstration, the cost model for SMOT validation mainly consists of labor and resources associated with modeling analyses, as well as the construction costs for the proposed BMPs. Table 7-1 summarizes the details.

Table 7-1. Cost model for SMOT validation.

Cost Element	Data To Be Tracked
Baseline characterization	Baseline data for input to MST, the detailed modeling methods, and the BMP Sizing Tool, costs associated with labor are tracked
Modeling analysis	Modeling analyses for the two installations, costs associated with labor and resources, and BMP construction costs are tracked

As indicated in Table 7-1, unique cost elements to SMOT validation include baseline characterization and modeling analyses. Details for each cost element are in the following sections.

7.1.1 Cost model element: Baseline characterization

The baseline characterization study consisted of watershed data compilation for input into SMOT and detailed watershed modeling analyses. The watershed data compiled in the Phase II demonstration include elevation contours, drainage network, land use, underlying soil type, and BMP siting constraints. Data received for the two installations was tracked through an Excel spreadsheet and the GIS files were compiled into a centralized geodatabase. Labor was tracked according to the type of personnel required to conduct the baseline characterization (field technician, engineer, program manager, etc.) and their associated labor hours.

7.1.2 Cost model element: Modeling analysis

Detailed modeling analyses were carried out at the two selected installations. The detailed modeling methods included DS, CS, and CS+O using spreadsheet models, SWMM, and SUSTAIN, respectively. BMP sizes following each of the modeling methods were compared against each other and the comparison results were used to validate MST component recommendations. A comprehensive survey of BMP constructions costs was completed for regions across the country from multiple sources to quantify the cost of constructing the simulated projects. Because material and labor costs can vary by region, sources and costs were organized geographically, and applied to the most proximal bases: northeast region for APG, and southeast region for NAS Key West (Table 7-2). The presented costs are for bioinfiltration units and are applied to the simulated BMPs on a per unit basis ($ per square foot).

Table 7-2. BMP construction costs by region

Region	Average Cost ($/sq ft)	References
Northeast	16.61	CRWA* (2010); Tetra Tech (2012b); USEPA (2016)
Southeast	28.58	City of Alexandria (2015); Texas A&M AgriLife Extension (2012); DNREC (2009)
Southwest	10.76	UF (2008)
Northwest	35.52	WSDE (2012); ISWEF (2008); PCA** (2011)
California	65.20	CASQA (2003)
*Charles River Watershed Association ** Minnesota Pollution Control Agency		

BMP sizing results from the most cost-effective modeling method, and BMP construction costs were also integrated into the BMP Sizing Tool. Data for the MST component, detailed modeling methods, and BMP Sizing Tool component were tracked in an Excel spreadsheet. Labor was tracked according to the type of personnel required to conduct the modeling analysis (modeler, engineer, program manager, etc.) and their associated labor hours.

7.2 Cost drivers

The components of SMOT that have been developed and stress tested can be implemented across a wide range of climates, development conditions, and installation characteristics. The detailed models used to perform the validation and inform the BMP Sizing Tool are publicly available. Therefore, the primary driver for impacting cost was data availability. If installations have all of the data needed to run SMOT, there should be no significant increase in costs. However, if data must be collected (e.g., rainfall data, infrastructure, soils, etc.), then those associated costs can impact the overall implementation effort. SMOT has been designed to incorporate national and publicly available data to the maximum extent feasible to minimize these added costs.

7.3 Cost analysis and Comparison

A cost analysis and comparison were completed for each installation. The cost of each modeling and development scenario includes the cost to design the BMPs and associated stormwater systems and the cost of final BMP construction. The design and incidental cost were determined by the type of personnel and estimated labor required to produce finished design plans and modeling analyses (field technician, surveyor, engineer, program manager, etc.) for the corresponding BMPs, stormwater systems, and modeling approach (DS, CS, CS+O). BMP costs were determined from completing a comprehensive regional analysis to determine planning-level region specific constructions costs (see Section 7.1.2).

7.3.1 APG

A cost analysis and comparison were completed for each modeling approach (DS, CS, CS+O) and development scenarios (development of 30%, 60%, and 90% of developable pervious area) on APG. For the subcatchment scale, in each simulation, the sum of the lumped and distributed BMP volume and drainage area are identical, indicating that they are equally capable of restoring hydrologic conditions when sized correctly. As a result, the BMP construction costs are identical between the lumped and distributed modeling approaches. However, the design and incidental costs are lower for the CS modeling approach due to less intensive modeling requirements. Table 7-3 lists the corresponding construction, design, and total costs for each scenario at the subcatchment scale.

Table 7-3. APG subcatchment-scale cost comparison.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Construction Cost to Meet AAFV	Design Storm	$1,794,358	$3,031,597	$4,203,719
	Lumped CS	$701,826	$2,119,948	$3,190,774
	Distributed CS+0	$701,826	$2,119,948	$3,190,774
	Design Storm	$861,292	$1,455,167	$2,017,785

		+30% Impervious	+60% Impervious	+90% Impervious
Design and Incidental Costs to Meet AAFV	Lumped CS	$378,986	$1,144,772	$1,723,018
	Distributed CS+0	$421,095	$1,271,969	$1,914,465
Total Cost to Meet AAFV	Design Storm	$2,655,650	$4,486,764	$6,221,504
	Lumped CS	$1,080,812	$3,264,719	$4,913,793
	Distributed CS+0	$1,122,921	$3,391,916	$5,105,239

For all of the subcatchment development scenarios at APG, the total cost needed to reduce the AAFV to predevelopment conditions was minimized when the BMP was lumped. These results indicate that the specific placement and distribution of BMPs do not generate a significant cost savings in a homogenous soil setting, and in fact, slightly increase the total cost due to higher design and incidental cost.

Similar results were observed for the subwatershed-scale models (Table 7-4) across all three development scenarios (30%, 60%, and 90% development). Regardless of spatial scale, the BMP sizes, and corresponding total cost, of the CS and CS+O simulations were within 10% of each other and BMP total costs for the DS approach are greater than the CS approach by 10%. These results confirm that optimization does not yield significant savings for APG (and slightly increase the total cost due to higher design and incidental costs) and that the recommendations from the MST and detailed modeling efforts are consistent at APG, satisfying the overarching performance objective (Table 7-4).

Table 7-4. APG subwatershed-scale cost comparison.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Construction Cost to Meet AAFV	Design Storm	$25,902,431	$40,445,416	$55,060,755
	Lumped CS	$5,715,900	$14,253,573	$24,889,487
	Distributed CS+0	$5,715,900	$14,253,573	$24,889,487
Design and Incidental Costs to Meet AAFV	Design Storm	$12,433,167	$19,413,800	$26,429,162
	Lumped CS	$3,086,586	$7,696,929	$13,440,323
	Distributed CS+0	$3,429,540	$8,552,144	$14,933,692
Total Cost to Meet AAFV	Design Storm	$38,335,598	$59,859,216	$81,489,917
	Lumped CS	$8,802,485	$21,950,502	$38,329,810
	Distributed CS+0	$9,145,439	$22,805,716	$39,823,179

7.3.2 NAS Key West

NAS Key West was selected as a site with high cost savings potential when the spatial optimization method is applied due to the largely heterogeneous soil distribution. MST confirmed this hypothesis by identifying the CS+O approach as generating significant cost savings. The costs of BMP implementation for the detailed modeling analyses below include both the subcatchment and subwatershed scale at all three development levels (30%, 60%, and 90% of developable pervious area). In all scenarios, the detailed models indicate that spatial optimization generates at least a 10% cost savings when the BMPs area is sized to meet the predevelopment AAFV, indicating that the CS+O approach is beneficial.

Table 7-5 lists the results for the subcatchment-scale modeling approach. The variable costs for achieving the predevelopment AAFV between the two BMPs can be attributed to the greater infiltrative capacity of the BMP on HSG A, which is able to percolate stormwater at a greater rate than the BMP on HSG D. These results indicate that strategically identifying and siting BMPs over HSG A soils at NAS Key West minimizes the total cost of achieving the predevelopment AAFV. Siting BMPs on HSG A soils reduces total costs on implementation by approximately 42% compared to siting BMPs on HSG D soils for all three development levels. Additionally, the spatially optimized BMP total cost was significantly less than what was needed to implement the design storm method.

Table 7-5. NAS Key West subcatchment-scale cost comparison.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Construction Cost to Meet AAFV	Design Storm	$3,411,149	$3,647,688	$3,859,329
	HSG A	$99,596	$211,641	$323,686
	HSG D	$174,292	$361,034	$560,225
Design and Incidental Costs to Meet AAFV	Design Storm	$1,637,351	$1,750,890	$1,852,478
	HSG A	$59,757	$126,984	$194,211
	HSG D	$104,575	$216,620	$336,135
Total Cost to Meet AAFV	Design Storm	$5,048,500	$5,398,579	$5,711,807
	HSG A	$159,353	$338,625	$517,897
	HSG D	$278,868	$577,654	$896,360

The subwatershed-scale area within Key West returned similar total cost savings. For each simulation there were over 10,000 unique combinations possible, meaning 10,000 different BMP sizing and siting opportunities in the plots. The following cost assessment is based on the scenario results presented in Table 6-5. The locating BMPs on HSG A reduced total costs by 10%, 31%, and 36% compared to locating BMPs on HSG D for development levels 30%, 60%, and 90% of developable pervious area, respectively (Table 7-6). These results again indicate that strategically identifying and siting BMPs over HSG A soils at NAS Key West minimizes the total cost of achieving the predevelopment AAFV, especially as development area increases. Additionally, the spatially optimized BMP total cost was significantly less than what was needed to implement the design storm method.

Table 7-6. NAS Key West subwatershed-scale cost comparison.

		+30% Impervious	+60% Impervious	+90% Impervious
BMP Construction Cost to Meet AAFV	Design Storm	$39,340,256	$40,946,234	$42,489,966
	HSG A	$510,427	$1,419,237	$2,278,249
	HSG D	$572,675	$2,054,159	$3,597,890
Design and Incidental Costs to Meet AAFV	Design Storm	$18,883,323	$19,654,193	$20,395,184
	HSG A	$306,256	$851,542	$1,366,949
	HSG D	$343,605	$1,232,495	$2,158,734
Total Cost to Meet AAFV	Design Storm	$58,223,578	$60,600,427	$62,885,150
	HSG A	$816,684	$2,270,779	$3,645,198
	HSG D	$916,279	$3,286,654	$5,756,625

8 Implementation Issues

MST, a major component of SMOT, recommends the most cost-effective modeling approach based on installation-specific information input by the user. As SMOT is applied at an installation, the user first prepares baseline watershed characteristics data that will be input into the toolbox. Although MST was developed to use readily available input characteristic data, the need for user input to inform baseline data about the installation being considered, specifically a long-term precipitation record (see Table 6-7), presents the most significant implementation issue for SMOT and its components. The video guide was developed to help users, but the user still must know how to develop precipitation time series for a minimum of a 10-year record. Most installations will likely have access to a robust record of rainfall; however, gauge distance from the area of interest, or the need to use multiple gauges to “fill-in” rainfall data may be required as an alternative method. Where rainfall data are unavailable, viable alternatives are available; for instance, a tool developed by Oregon State University’s Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group, is a viable alternative. PRISM is a remote sensing, gridded raster product that is able to provide climatic data for virtually any region within the United States (http://prism.oregonstate.edu/).

Overall, SMOT presents a solid package that DoD installations can rely on for comprehensive support to stormwater regulation compliance. The toolset is able to choose a cost-effective modeling approach for sizing BMPs in an installation, provide guidance on detailed modeling analysis, guide efficient implementation, and then provide a tracking and accounting tool for long-term stormwater management. As limitations in detailed modeling capabilities are overcome, the toolset will be able to provide a completely streamlined process for cost-effective stormwater regulation compliance support to all DoD installations.

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Acronyms and Abbreviations

Abbreviation	Term
AAFV	Average Annual Flow Volume
AFB	Air Force Bases
AFCEC	Air Force Civil Engineer Center
APG	Aberdeen Proving Ground
BMP	Best Management Practice
BMPDSS	BMP Decision Support System
ERDC-CERL	Construction Engineering Research Laboratory
CRWA	Charles River Watershed Association
CS	Continuous Simulation
CWASSC	Clean Water Act Service Steering Committee
DEM	Digital Elevation Model
DoD	Department of Defense
DS	Design Storm
EISA	Energy Independence and Security Act
EPA	(U.S.) Environmental Protection Agency
ER	Environmental Restoration
ESTCP	Environmental Security Technology Certification Program
HRU	Hydrologic Response Unit
HSG	Hydrologic Soils Group
HSPF	Hydrological Simulation Program - Fortran
IGI&S	Installation Geospatial Information and Services
LID	Low Impact Development
METF	Maximum Extent Technically Feasible
MST	Model Selection Tool
NAS	Naval Air Station
NCDC	National Climate Data Center
NOAA	National Oceanic and Atmospheric Administration
NZP	Net Zero Planner
PCA	Pollution Control Agency
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SERDP	Strategic Environmental Research and Development Program
SMOT	Stormwater Management Optimization Toolbox
SSURGO	Soil Survey Geographic (database)]
STORM	Storage, Treatment, Overflow, Runoff Model
SUSTAIN	System for Urban Stormwater Treatment Analysis and Integration
SWMM	Stormwater Management Model
TMDL	Total Maximum Daily Load
UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency

Appendix A: EPA Guidance for Estimating the 95th Percentile Rainfall

In the technical guidance for complying with EISA section 438 regulations (USEPA 2009a), a four-step procedure for determining the 95th percentile rainfall at a location was provided. The following procedure is directly from the EPA technical guidance.

1. Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv=.
2. Remove data for small rainfall events of 0.1 in. or less and snowfall events that do not immediately melt from the dataset. These events should be deleted since they do not typically cause runoff and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate.
3. Using a spreadsheet or simple statistical package, sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number/total number of events). For example, if there were 1,000 rainfall events and the highest rainfall event was a 4-in. event, then 999 events (or a percentile of 999/1000, or 99.9%) are less than the 4-in. rainfall event.
4. Use the rainfall event at 95% as the 95th percentile storm event.

Appendix B: Example Likert Survey

		Strongly Disagree		Disagree	Neutral	Agree	Strongly Agree
#	Question	1		2	3	4	5
1	Overall design of Model Selection Toolbox is user friendly						
2	User manual is clear, concise, and easy to follow						
3	Resources and expertise required to run Model Selection Toolbox is reasonable						
4	Data requirements for the tool are readily available						
5	Data input to run Model Selection Toolbox is easily accomplished						
6	Data input to run Model Selection Toolbox is appropriate						
7	Model Selection Toolbox consistently chooses most cost-effective modeling approach for a variety of site conditions						
8	Total BMP footprint are substantially reduced						
9	Toolbox output is easily understood and interoperated						
10	Toolbox output is easily adjusted for installation needs						
11	Time spent in analysis is less than other currently used modeling tools						
12	Cost benefit of the Model Selection Toolbox is worth effort						
15	Final results are acceptable						

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14. ABSTRACT
As stormwater regulations for hydrologic and water quality control become increasingly stringent, Department of Defense (DoD) facilities are faced with the daunting task of complying with multiple laws and regulations. This often requires facilities to plan, design, and implement structural best management practices (BMPs) to capture, filter, and/or infiltrate runoff—requirements that can be complicated, contradictory, and difficult to plan. This project demonstrated the Stormwater Management Optimization Toolbox (SMOT), a spreadsheet-based tool that effectively analyzes and plans for compliance to the Energy Independence and Security Act (EISA) of 2007 pre-hydrologic conditions through BMP implementation, resulting in potential cost savings by reducing BMP sizes while simultaneously achieving compliance with multiple objectives. SMOT identifies the most cost-effective modeling method based on an installation's local conditions (soils, rainfall patterns, drainage network, and regulatory requirements). The work first demonstrated that the Model Selection Tool (MST) recommendation accurately results in the minimum BMP cost for 45 facilities of widely varying climatic and regional conditions, and then demonstrated SMOT at two facilities.

15. SUBJECT TERMS
Storms, Runoff, Military bases, Water quality management, Hydrology

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