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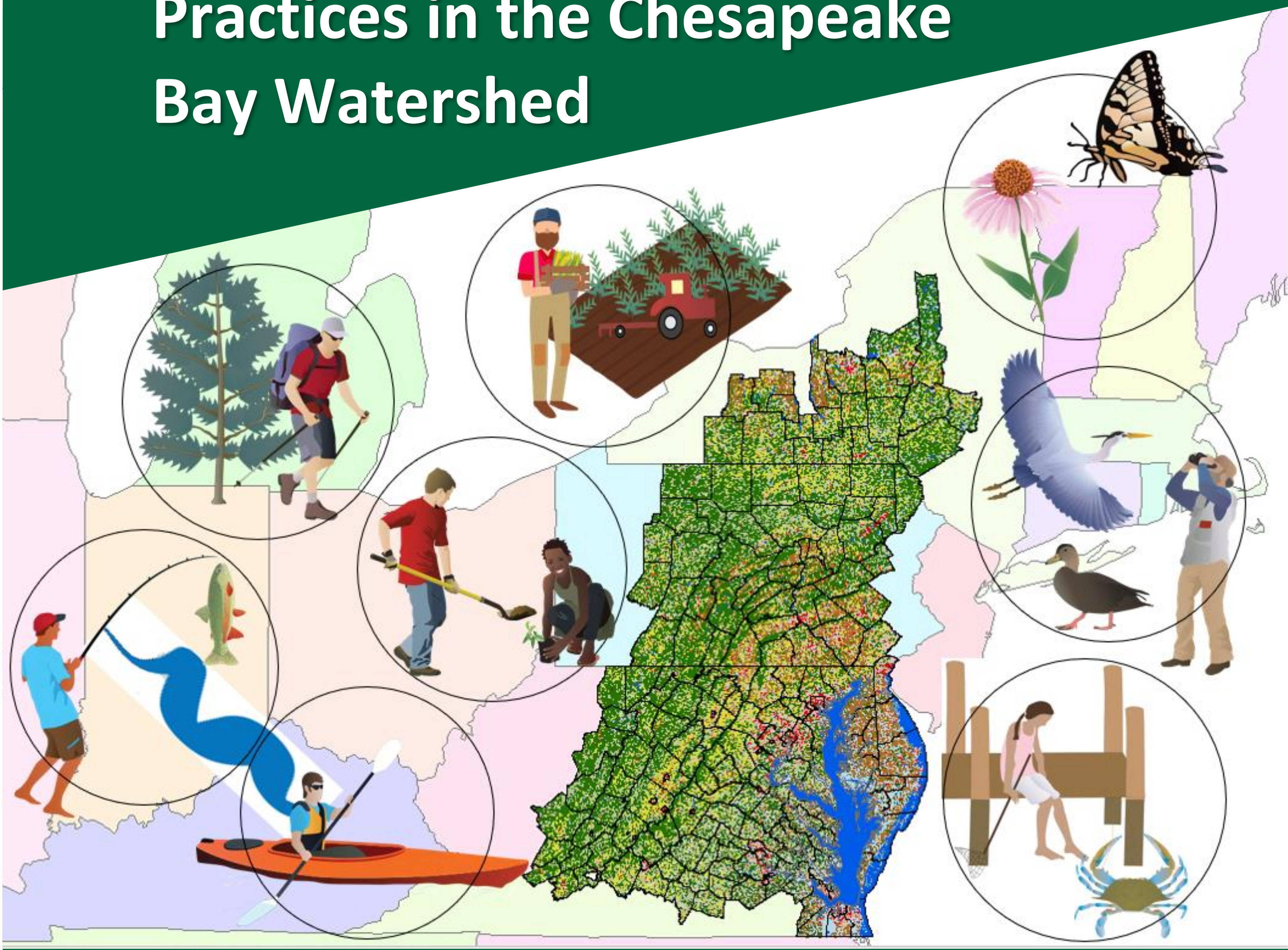

Office of Research and Development
Center for Environmental Measurement and Modeling

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Quantifying Ecosystem Services Benefits of Restoration and Conservation Best Management Practices in the Chesapeake Bay Watershed

By

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Notice and Disclaimer

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This document has been subjected to the Agency’s peer and administrative review and has been approved for publication as an EPA document. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names, commercial products, or services constitute endorsement or recommendation for use.

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Data files associated with this report will be available in EPA ScienceHub: https://catalog.data.gov/dataset/epa-sciencehub

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US Geological Survey National Land Cover Database

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Abbreviations and Acronyms

Throughout this report, the term "ecosystem goods and services" is often abridged to "ecosystem services" and may include either intermediate or final ecosystem goods and services (FEGS).

Acronyms and abbreviations used in this report include the following.

ACRONYM	FULL NAME
BMP	Best Management Practice
C	Carbon
CAST	Chesapeake Assessment Scenario Tool
CBP	Chesapeake Bay Program
CBPO	Chesapeake Bay Program Office
EPA	Environmental Protection Agency
FEGS	Final Ecosystem Goods and Services
GIS	Geographic Information System
GIT	Goal Implementation Teams
ICR	Impervious Cover Removal
ICD	Impervious Cover Disconnection
INVEST	Integrated Valuation of Ecosystem Services and Trade-offs
I-TREE	Tools for Assessing and Managing Forests and Community Trees
LGAC	Local Government Advisory Committee
LRS	Land River Segment
LULC	Land Use Land Cover
NESCS	National Ecosystem Services Classification System
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Science
STAR	Scientific, Technical Assessment & Reporting
TMDL	Total Maximum Daily Load
WIP	Watershed Implementation Plan

Executive Summary

Background

The Chesapeake Bay and its watershed have been the focus of restoration efforts since the 1980s when the first watershed agreement was signed. In 2010 a Total Maximum Daily Load (TMDL) was established to reduce nitrogen, phosphorus and sediment loads into the Bay. In response, jurisdictions in six states and Washington, D.C. created Watershed Implementation Plans (WIPs) that outlined best management practices (BMPs) to address sediment and nutrient impairments and improve water quality standards in the Bay. In 2014 a new Chesapeake Bay Watershed Agreement was adopted that included headwater states for the first time and outlined numeric goals for implementation of several BMPs focused on restoration and conservation of vital habitats. At the watershed scale, however, implementation goals associated with vital habitats are lagging, especially in upstream areas of the watershed.

Map of the Chesapeake Bay watershed. Polygons are county boundaries from six states and DC within the watershed.

One potential way to improve progress toward Watershed Agreement goals is to demonstrate how these actions may align with the priorities of local communities upstream in the watersheds where they would be implemented. This project extends beyond water quality outcomes by identifying and quantifying additional ecosystem services benefits that may result from habitat restoration and conservation related BMPs.

Identifying Focal BMPs and Priority Ecosystem Services

We reviewed existing management documents and worked with Chesapeake Bay Program partners to generate a target list of BMPs based on the following criteria: 1) related to Watershed Agreement goals that are lagging in implementation, 2) related to habitat restoration, creation, or conservation, and 3) likely relevant to upstream or headwater communities. A total of eleven BMPs were selected: agricultural forest buffer, agricultural grass buffer, agriculture tree planting, cover crops, forest conservation, impervious surface reduction, urban forest buffers, urban forest planting, urban tree planting, wetland creation, and wetland restoration.

Next, we used the National Ecosystem Services Classification System (NESCS Plus), a review of Chesapeake Bay planning documents, and feedback from partners to identify a comprehensive list of ecosystem services provided by each BMP, and the potential users (or beneficiaries) most likely to benefit from those ecosystem services (Rossi et al., 2022a). We used the Final Ecosystem Goods and Services Scoping Tool, in combination with a review of existing management documents and

Chesapeake Bay Program partner feedback, to assign importance weights to ecosystem services and generate a prioritized list for further assessment. The highest prioritized ecosystem services had the potential to be provided by multiple BMPs and had broad relevance across many different stakeholder groups.

Quantifying Ecosystem Services Production

For each priority ecosystem service, we identified candidate metrics based on the availability of data and models to be able to translate information on biological condition (i.e., acres of BMP implementation) into potential supply of ecosystem services. These models, known as ecological or ecosystem service production functions, can range from simple lookup tables to statistical models to complex biophysical models.

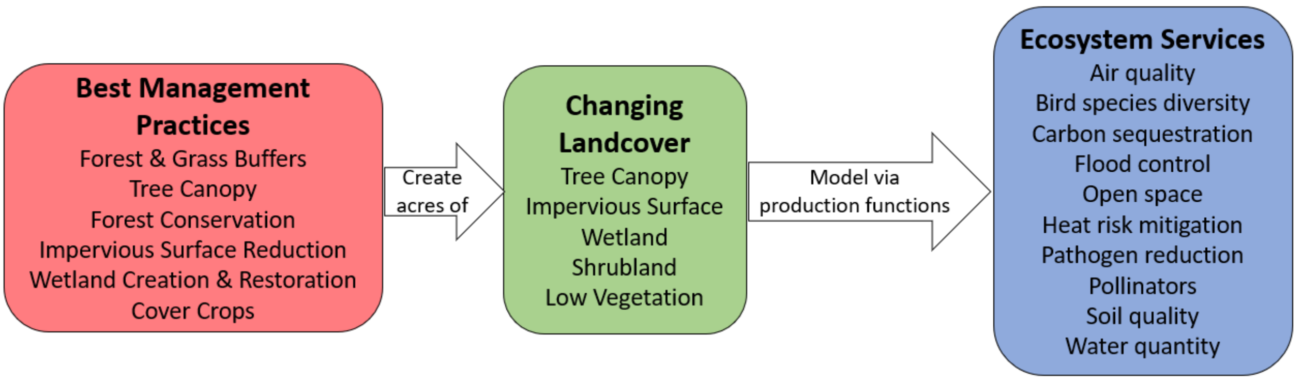


Diagram illustrating assessment framework translating acres of BMP implementation into landcover and ecosystem services via production function models.

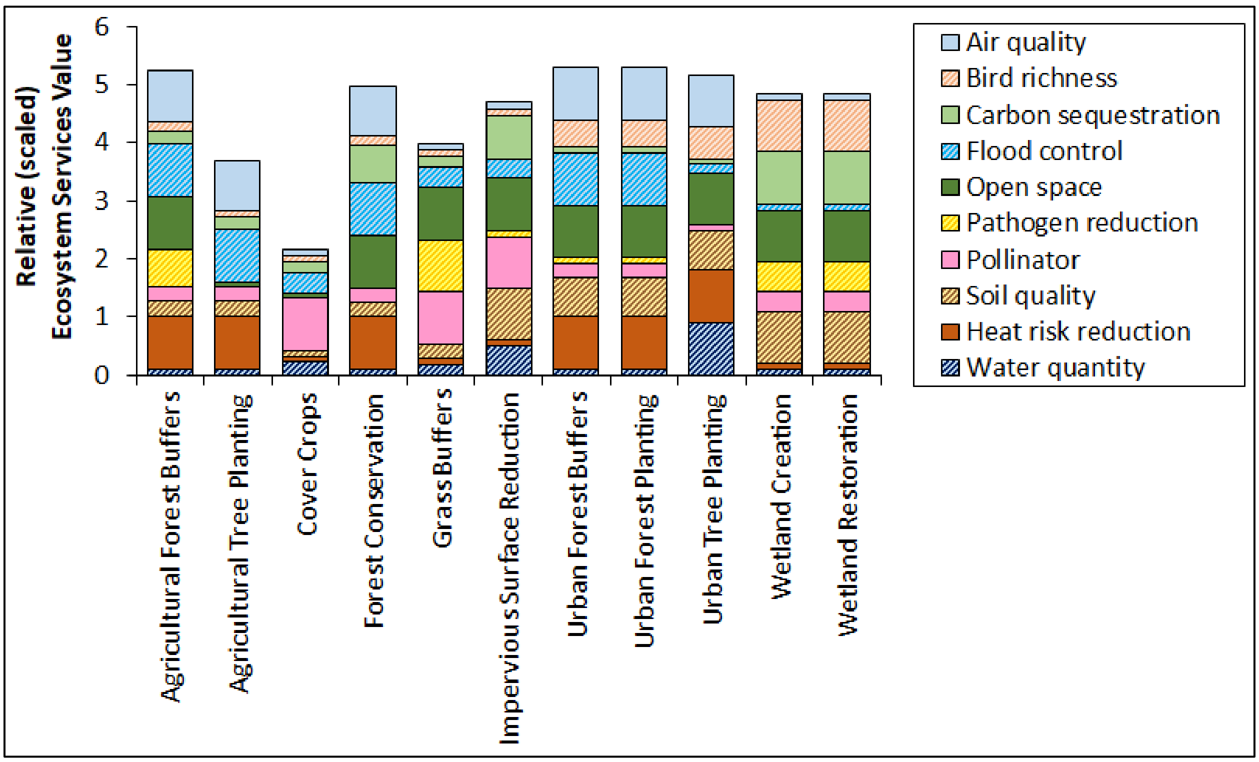
In general, we assumed each of the target BMPs would result in new acres of landcover based on the Chesapeake Bay Conservancy 2013-2014 landcover types assigned in the Chesapeake Assessment Scenario Tool (CAST) (e.g., natural tree canopy, low vegetation, wetland), and reviewed literature to assemble metrics of ecosystem services supply by landcover type, reviewed existing models to translate landcover into ecosystem services supply, or used available data to generate statistical relationships between known acres of landcover and observed measures of ecosystem services.

Table of top priority ecosystem services identified, and metrics and methods to quantify them.

Service	Metric	Quantification Method
Air quality	Removal rates of CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2	Air pollutant removal rates in urban and rural areas obtained from i-Tree and multiplied by acres of tree cover
Bird species diversity	Bird species richness (numbers per acre)	Statistical regressions used to generate species area curves that relate increasing acres of land cover type to potential bird species richness, obtained from USGS GAP
Carbon sequestration	Rates of carbon sequestration into soil	Average rates of burial of atmospheric carbon into soil (i.e., in support of mitigating climate change) by landcover type, obtained from COMET-Planner and literature review, multiplied by acres of landcover
Flood control	Maximum rainwater retention	Curve number method based on landcover and soil type (USDA and NRCS 1986)

Open space	Acres of greenspace per capita	Acres of landcover identified as wetland, tree canopy, shrubland, and low vegetation per capita
Heat risk mitigation	Reduction in air temperature due to presence of tree canopy	Statistical regressions to relate acres of tree canopy to summer air temperatures
Pathogen reduction	Removal efficiency of fecal indicator bacteria	Fecal indicator bacteria removal efficiencies obtained from literature review, multiplied by acres of landcover type
Pollinators	Index of pollinator habitat suitability	Uses the InVEST pollinator model to assign index of habitat suitability based on land cover, and characteristics of pollinators such as nesting and foraging distance
Soil quality	Carbon stock in soil	Carbon stock estimates by land cover type obtained from literature review and multiplied by acres of land cover
Water quantity	Annual surface water flow	Obtained for each land cover type from the Chesapeake Assessment Scenario Tool (CAST) hydrological model

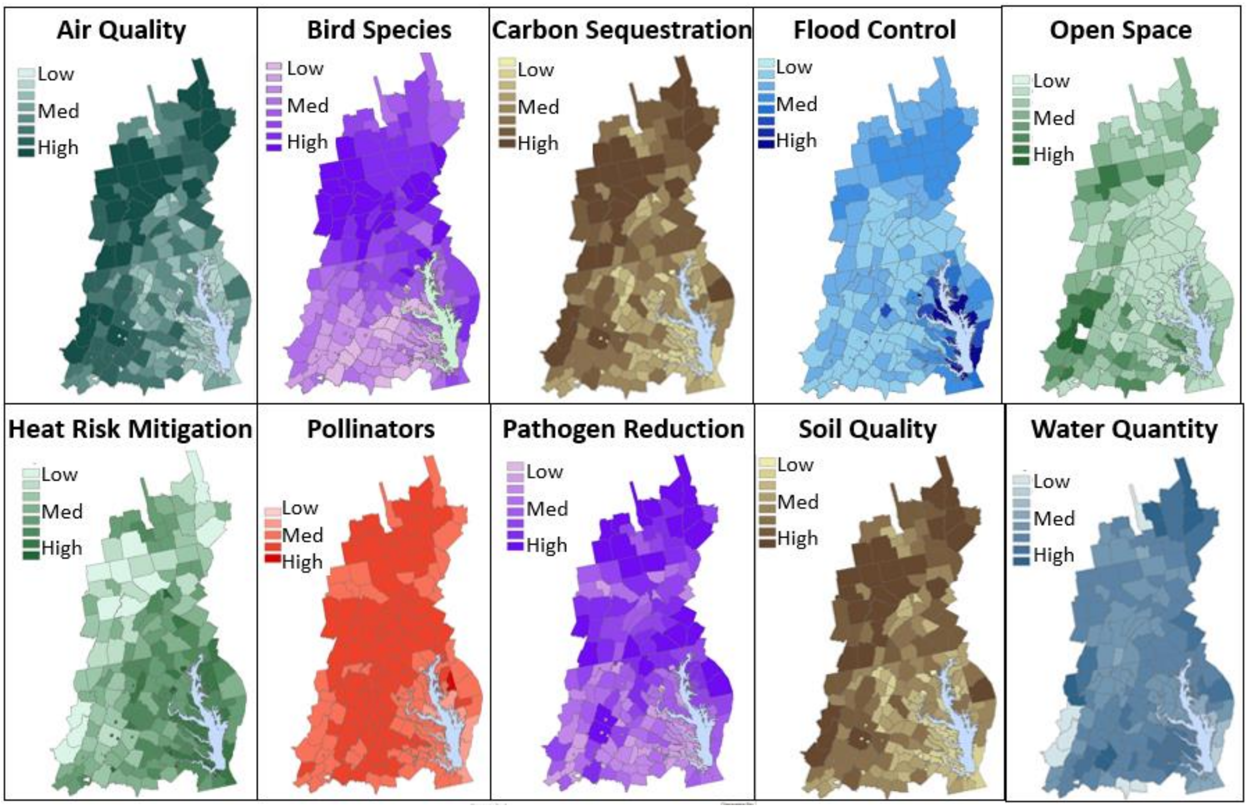
Models were used to quantify potential supply of ecosystem services with acres of implementation for each of the eleven focal restoration or conservation related BMPs.



Relative value of each of the ten ecosystem services, scaled from 0.1-0.9 for each focal BMP based on the minimum and maximum estimated value for each ecosystem service.

Communicating Benefits of BMP Implementation

This information is being used to help communicate the additional benefits, beyond Bay water quality improvements, that may be associated with BMPs in the watershed. The models and data are designed to work with existing Chesapeake Bay Program tools, including the Chesapeake Assessment Scenario Tool (CAST), a spatial modeling tool that lets users estimate nutrient reductions from BMPs. Results are also being integrated into the Watershed data dashboard, which lets users see information for each county in the watershed, to potentially target areas where ecosystem services could be improved.



Maps of baseline ecosystem services values for counties in the Chesapeake Bay watershed based on 2013/2014 landcover data. Intensity of colors indicate the counties with the lowest to highest ecosystem services value.

Quantifying ecosystem services for lagging implementation actions and connecting them with stakeholder interests can help communities understand benefits and tradeoffs of different BMPs, thus empowering communities to participate in restoration efforts in ways that resonate with them and address their own local priorities.

Chapter 1. Introduction

1.1. Background

The Chesapeake Bay has been undergoing restoration efforts since the 1980s when the first watershed agreement was signed by Maryland, Pennsylvania, Virginia, and the District of Columbia (Boesch et al., 2001). In 2010 a Total Maximum Daily Load (TMDL) was established to reduce nitrogen (N), phosphorus (P) and sediment loads into the Bay (EPA, 2010). As a result, all jurisdictions comprising the Bay's watershed (Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia; and District of Columbia) created Watershed Implementation Plans (WIPs) that outlined best management practices (BMPs) and controls to be implemented by 2017 and 2025 to address sediment and nutrient impairments. In 2014 a new Chesapeake Bay Watershed Agreement (Watershed Agreement) was adopted, which included headwater states of New York, West Virginia, and Delaware for the first time. To meet the TMDL and Watershed Agreement goals, restoration based BMPs could be implemented; however, implementation of several BMPs are currently below levels required to achieve Watershed Agreement Outcomes (Chesapeake Bay Program, 2020; Chesapeake Bay Program Web Team, 2020).

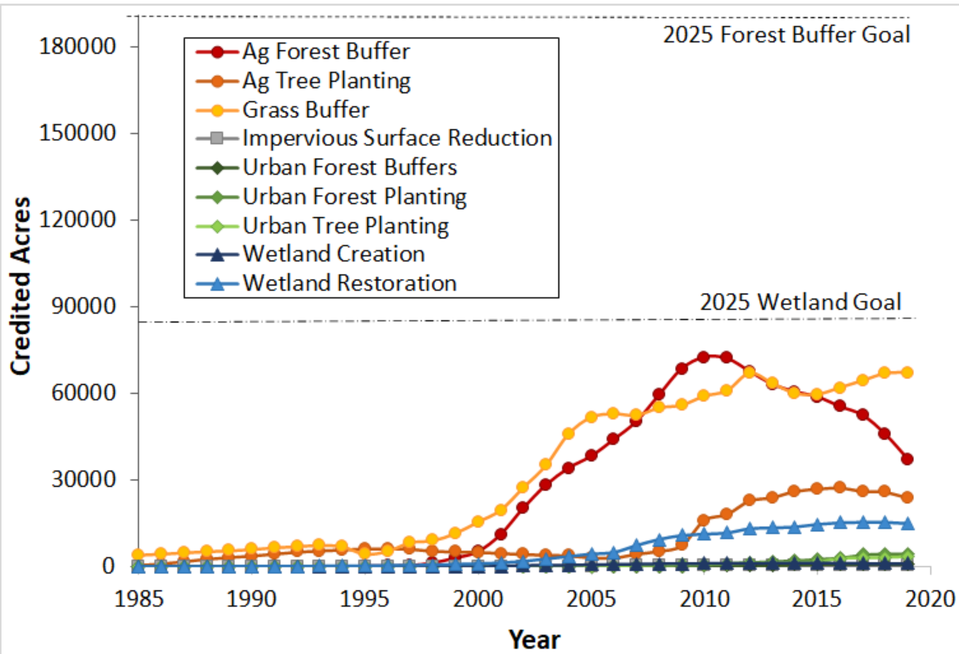


Figure 1.1. Credited acres of select BMPs through 2019. Data from CAST (https://cast.chesapeakebay.net/). The dashed lines represent the Wetland Outcome Acre goal (85,000 acres by 2025) and the Forest Buffer Outcome goal (190,557 acres of buffer across all states by 2025).

One potential way to improve implementation of lagging BMPs is to demonstrate how these actions may align with the priorities of local communities where they need to be implemented. Quantifying ecosystem services for lagging actions and connecting them with stakeholder interests can help communities understand impacts, benefits, and tradeoffs of different BMPs, empowering communities to participate in restoration efforts in ways that resonate with them and address their priorities.

Previous work in the Chesapeake Bay watershed has explored the potential for communication and quantification of additional benefits or ecosystem services that will be provided by the TMDL. For example, Wainger et al. (2015) estimated the potential of the TMDL to provide ecosystem services such as pathogen reduction and ecosystem resilience but this analysis does not necessarily quantify how specific BMPs provide those services. Another study identified the potential multiple benefits of water quality management practices by ranking management actions and how likely they were to provide certain co-benefits (Tetra Tech, 2017). Here, we build upon this previous work to quantify how individual BMPs may provide several ecosystem services.

1.2. Purpose

The objective of this project is to identify, prioritize, and quantify ecosystem services associated with restoration BMPs particularly relevant to communities far removed from the Bay, with the goal to provide estimates of ecosystem service supply due to BMP implementation at the finest scale at which BMPs are reported (county level). We worked with Chesapeake Bay Program Office (CBPO) and their partners (e.g., Scientific, Technical Assessment, and Reporting (STAR) team, Local Government Advisory Committee (LGAC), and Goal Implementation Teams (GITs) and their workgroups) to select a short list of BMPs to focus on (**Chapter 2**), which were related to conservation and restoration, and were relevant to upstream communities.

We worked with CBPO and their partners to identify ecosystem services and create a prioritized list of 14 ecosystem services to quantify for each of the BMPs selected (Rossi et al., 2022a). We then identified metrics to quantify those ecosystem services (Rossi et al., 2022a) to compare provision of ecosystem services between BMPs and create baseline estimates of ecosystem services for each county in the watershed (**Chapter 3**). In general, we assumed each of the target BMPs would result in new acres of landcover (e.g., natural tree canopy, low vegetation, wetland), and applied literature- and data-based models to translate landcover into ecosystem services supply. This kind of landcover-based approach allows compatibility with landcover-based tools or assessments of acres of habitat, although ultimately ecosystem services gained would depend on what landcover the BMP is replacing, as well as the characteristics and quality of the newly implemented landcover.

This project also recognizes that BMP implementation targets, as well as the ecosystem services gained through BMP implementation, contribute to accomplishment of Watershed Agreement Outcomes (**Chapter 4**). We have built on previous work (e.g., Tetra Tech, 2017) to identify links between watershed outcomes and the BMPs and ecosystem services we focused on (Fig. 1.2). BMPs can lead to ecosystem services benefits that help achieve and support watershed outcomes. For example, forest buffers (BMP) can help to reduce air and water temperatures through shading (Ecosystem Service), creating more favorable habitat for brook trout (Outcome). Alternatively, achievement of outcomes, such as tree canopy, can help support additional ecosystem services benefits, such as buffering air pollution or creating bird habitat. These benefits, in turn, may or may not be related to additional outcomes, as part of a complex system of interacting relationships.

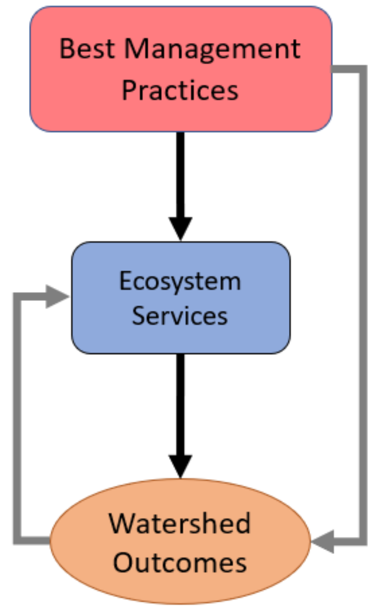


Figure 1.2 BMPs provide ecosystem services that may contribute to meeting watershed outcomes, which in turn may provide additional ecosystem service benefits.

1.3. What Does this Project not Encompass?

Chesapeake Bay watershed plans encompass hundreds of BMPs. This work is focused on a subset of BMPs that were scoped to be relevant to headwater communities, that were lagging in implementation, and lean towards nature based BMPs. Additional work would need to be done to estimate potential ecosystem services benefits for the full suite of BMPs. Our approach to ecosystem services quantification is non-monetary—we do not attempt to assign monetary values to ecosystem services, but this work is the first step in the valuation process.

1.4. Report Structure

Because users may be interested in BMPs, ecosystem services, and/or watershed outcomes, we have organized the bulk of this report into the following sections: Best Management Practices (**Chapter 2**), Ecosystem Services (**Chapter 3**), and Watershed Outcomes (**Chapter 4**). In each section, there is summary information and a single fact sheet for each individual BMP, ecosystem service, and watershed outcome we have focused on. Details on methods used to quantify each ecosystem service are included in **Appendix A**.

Chapter 2. Best Management Practices

2.1. What are Best Management Practices (BMPs)?

The Best Management Practices (BMPs) focused on here are actions that can be taken to prevent or reduce nutrient and sediment pollution from entering local waterways. Typically, BMPs are implemented to reduce three main pollution sources: wastewater, stormwater (or loads from the urban sector) and runoff from the agriculture sector. In the Chesapeake Bay Watershed, there are hundreds of BMPs that have been vetted and approved for implementation to help meet the federally mandated Total Maximum Daily Load (TMDL) for the Bay (Chesapeake Bay Program, 2018).

2.1.1. How did we arrive at our short list of BMPs?

For the purposes of our report, we created a short list of BMPs to focus on based on the following criteria: 1) related to Watershed Agreement goals 2) implementation is lagging, 3) related to habitat restoration and/or creation, and 4) likely relevant to upstream/headwater communities (Rossi et al., 2022a). We reviewed CBPO management documents to develop an initial list of BMPs. We scoped our initial list by holding discussions with CBP partners representing all regions of the watershed, and partners leading CBP's efforts on different components of the Watershed Agreement. Based on partner feedback and data availability, we finalized a list of 11 BMPs to move forward with for ecosystem services assessment: agricultural forest buffers, agricultural grass buffers, agricultural tree planting, cover crops, forest conservation, impervious surface reduction, urban forest buffers, urban forest planting, urban tree planting, wetland creation, and wetland restoration.

2.1.2. BMP Factsheet Overview

For each BMP, we have created a factsheet containing the following:

- Description of BMP
- Current implementation acres of the BMP
- Additional ecosystem services benefits (described in **Chapter 3**) of the BMP
- Watershed Agreement outcomes (described in **Chapter 4**) that may benefit from the BMP

2.2. Agricultural Forest Buffers

What is an agricultural forest buffer?

Forest buffers create forest like habitat that may provide many ecosystem services. They are linear wooded areas placed between the edge of a field and streams, rivers, or tidal waters that help filter nutrients, sediments and other pollutants from runoff as well as remove nutrients from groundwater. The recommended buffer width is 100 feet, with a 35 feet minimum width required (Chesapeake Bay Program, 2018). Agricultural forest buffers are placed on agricultural land (Chesapeake Bay Program, 2018).

Forest Buffers are currently implemented at varying acreages across the watershed with the largest implementation in Worcester County, Maryland (Fig. 2.2.1), based on county-level reporting data.

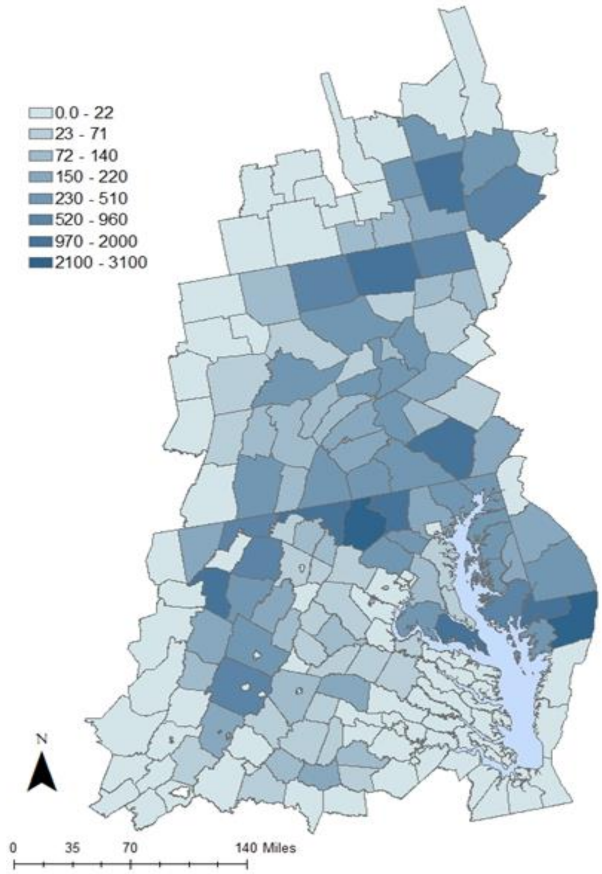


Figure 2.2.1 Cumulative acres of agricultural forest buffer BMPs (fenced and un-fenced) implemented at the county level through 2019.

What are the additional benefits of implementing an agricultural forest buffer BMP?

Agricultural forest buffer BMPs help reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated forest buffers to be particularly important for improving air quality, heat risk reduction through shading, providing natural open space for habitat or recreational uses, and controlling flooding (Fig. 2.2.2).

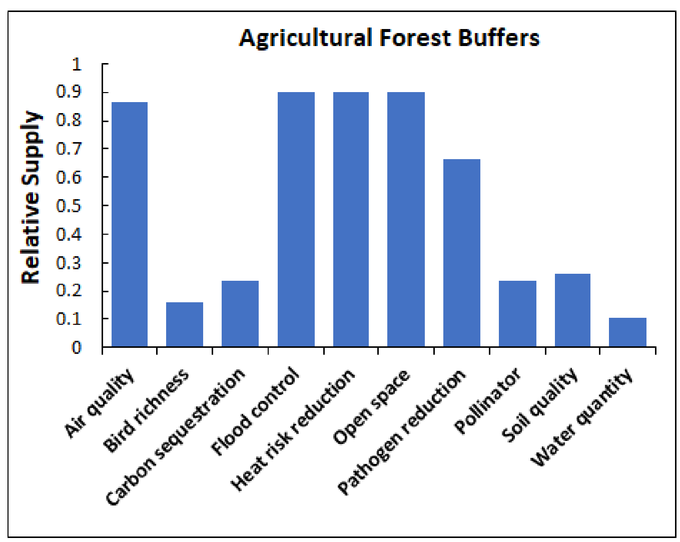


Figure 2.2.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by agricultural forest buffers relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 35 potential ecosystem services provided by agricultural forest buffer BMPs that would benefit 37 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.2.3. For example, habitat for birds and pollinators may benefit wildlife viewers and farmers.

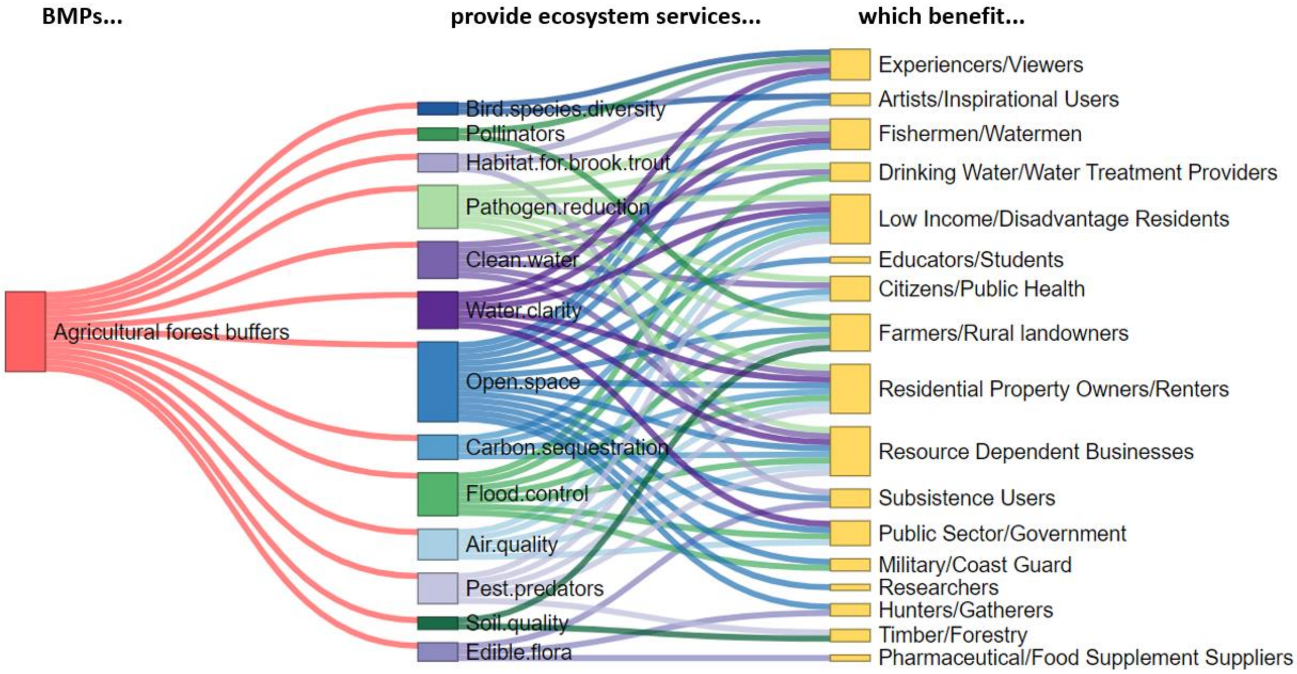


Figure 2.2.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from agricultural forest buffers?

We identified a direct connection between agricultural forest buffers and several Chesapeake Bay Watershed Agreement outcomes (Table 2.2.1). Outcomes are further described in Chapter 4.

Table 2.2.1. Connections between the agricultural forest buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like agricultural forest buffers, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Agricultural forest buffers can help create black duck habitat.
Blue Crab Abundance	Agricultural forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Agricultural forest buffers can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through agricultural forest buffers can enhance resilience to flooding and coastal erosion.
Fish Habitat	Agricultural forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.

Forest Buffer	Acres of riparian forest buffers, and their capacity to provide water quality and habitat benefits, can be increased through agricultural forest buffers.
Healthy Watersheds	Agricultural forest buffers, by increasing trees and forests, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Agricultural forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through creation of agricultural forest buffers ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through agricultural forest buffers allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing trees and forest through agricultural forest buffers can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Agricultural forest buffers lead to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Agricultural forest buffers can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Wetlands	Agricultural forest buffers at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_A.12_Forest-Buffers-and-Grass-Buffers_.pdf

NRCS BMP factsheet: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255022.pdf

2.3. Agricultural Tree Planting

What is agricultural tree planting?

Agricultural tree planting includes any trees planted on agricultural land, except those specifically used to establish riparian forest buffers (see Section 2.2). Tree planting targets lands that are highly erodible or identified as critical resource areas. Currently, tree planting BMPs are implemented throughout the watershed with an average implementation of 121 acres (Chesapeake Bay Program, 2018).

Implementation of tree planting varies throughout the watershed with Sussex County, Delaware having the highest acreage in 2019 (Fig. 2.3.1), based on county-level reporting data.

What are the additional benefits of implementing agricultural tree planting BMP?

Agricultural tree planting helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated tree planting to be particularly important for reducing heat risk through shading, improving air quality, and helping to control flooding (Fig. 2.3.2).

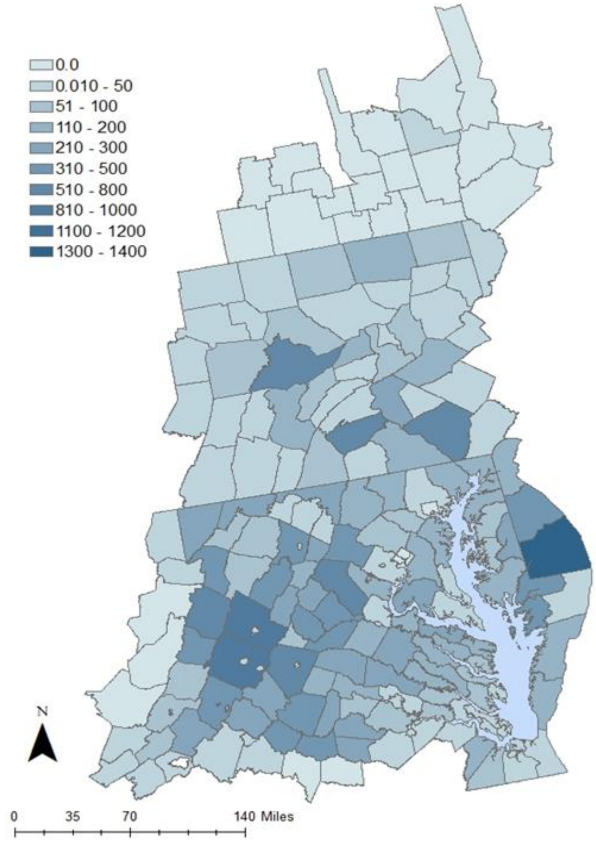


Figure 2.3.1. Cumulative acres of agriculture tree planting BMPs implemented by county through 2019.

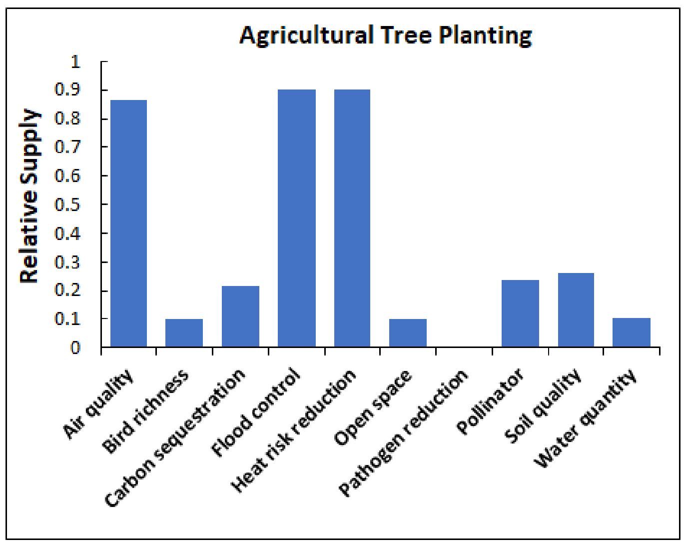


Figure 2.3.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by agricultural tree planting relative to the minimum (0.1) and maximum (0.9) across all focal BMPs. Missing values are due to lack of data to quantify that particular ecosystem service.

In total, we identified 30 potential ecosystem services provided by agricultural tree planting BMPs that would benefit 33 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.3.3. For example, tree planting helps to sequester carbon from the atmosphere and buffer air pollutants, improving air quality for residents.

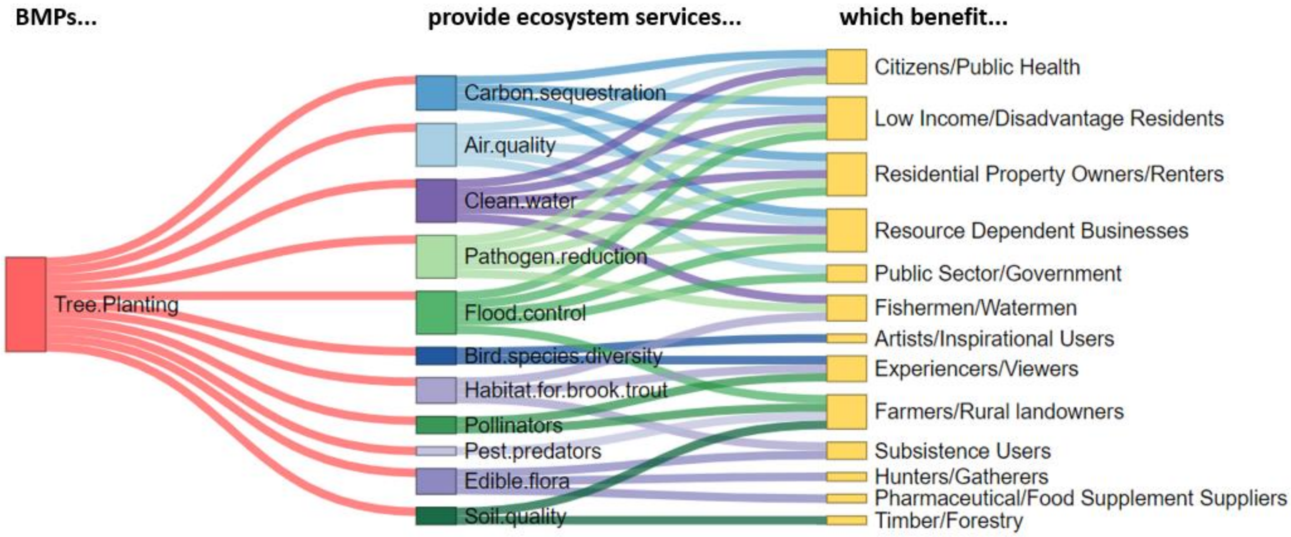


Figure 2.3.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from agricultural tree planting?

We identified a direct connection between agricultural tree planting and several Chesapeake Bay Watershed Agreement outcomes (Table 2.3.1). Outcomes are further described in Chapter 4.

Table 2.3.1. Connections between agricultural tree planting BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like agricultural tree planting, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Agricultural tree planting can help create black duck habitat.
Brook Trout	Agricultural tree planting can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through agricultural tree planting can enhance resilience to flooding and coastal erosion.
Fish Habitat	Agricultural tree planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Healthy Watersheds	Agricultural tree planting, by increasing trees, helps to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.

Oyster	Agricultural tree planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Stream Health	Increasing trees through agricultural tree planting can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Agricultural tree planting leads to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen, and traps the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Agricultural tree planting can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Wetlands	Agricultural tree planting at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet:

https://www.chesapeakebay.net/documents/BMP-Guide_A.23_Tree-Planting-Agricultural_.pdf

NRCS factsheets:

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1291420.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255014.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026460.pdf

https://www.fsa.usda.gov/Internet/FSA_File/crpcp3a.pdf

2.4. Cover Crops

What are cover crops?

Cover crops are short-term crops grown after the main cropping season to reduce nutrient and sediment losses from the farm field. Traditional cover crops may not receive nutrients in the fall and may not be harvested in the spring. Commodity cover crops are harvested (e.g., winter cereal). There are many variations in cover crop species and their management. For example, the timing of planting can vary (early, standard, or late) in relation to the average frost date for the region or the method of planting may differ (e.g., aerial or drilled) (Chesapeake Bay Program, 2018).

As of 2019, implementation of cover crops varied across the watershed with the largest implementation in Kent County, Maryland (Fig. 2.4.1), based on county-level reporting data.

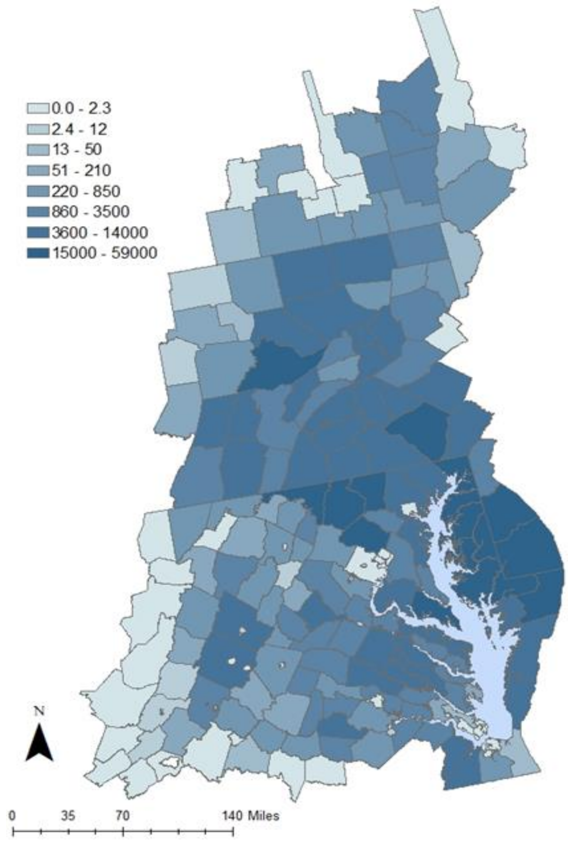


Figure 2.4.1. Annual acres of cover crop implementation at the county level in 2019.

What are the additional benefits of implementing a cover crop BMP?

Cover crops help reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated cover crops to be particularly important for creating pollinator habitat (Fig. 2.4.2).

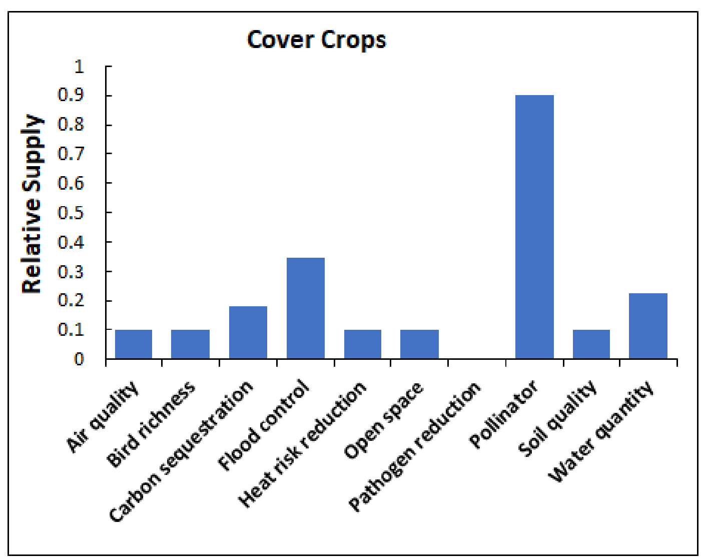


Figure 2.4.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by cover crops relative to the minimum (0.1) and maximum (0.9) across all focal BMPs. Missing values are due to lack of data to quantify that particular ecosystem service.

In total, we identified 17 potential ecosystem services provided by cover crops that would benefit 19 user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.4.3. For example, cover crops may provide improved soil quality for farmers which could reduce fertilizer use and costs and improve crop outputs. Cover crop BMPs also provide habitat for pollinators which could benefit wildlife viewers interested in pollinators and farmers who require some crops to be pollinated.

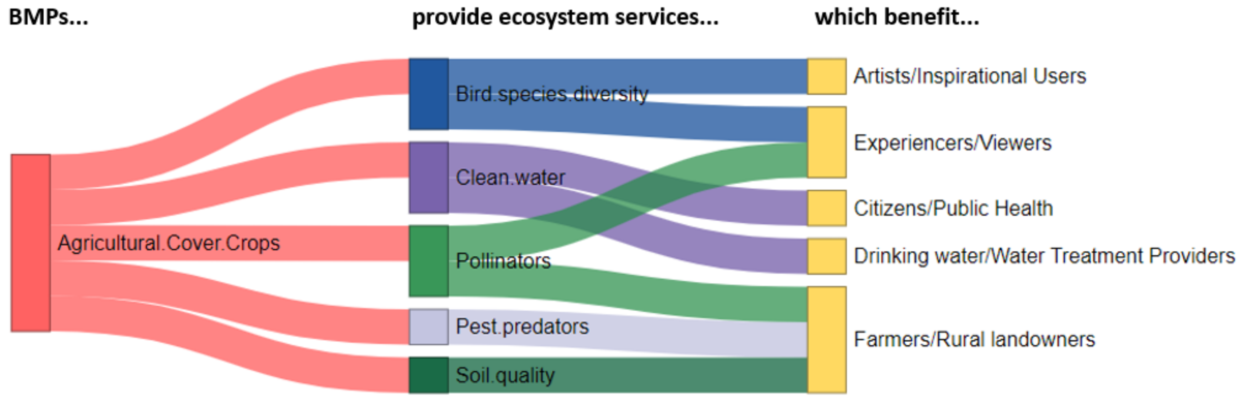


Figure 2.4.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from cover crops?

We identified a direct connection between cover crops and several Chesapeake Bay Watershed Agreement outcomes (Table 2.4.1). Outcomes are further described in Chapter 4.

Table 2.4.1. Connections between the cover crop BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like cover crops, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Fish Habitat	Cover crops can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Oyster	Cover crops can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Submerged Aquatic Vegetation (SAV)	Cover crops lead to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen, and traps the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Cover crops can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_A.4_Cover-Crops-Traditional_.pdf

NRCS factsheet: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263481.pdf

2.5. Forest Conservation

What is forest conservation?

Forest conservation is a land policy BMP. Organizations and governments are proactively pursuing a variety of actions to conserve forests, which provide benefits to wildlife, human safety, and water quality. Example priority areas include riparian zones, large contiguous forest tracts, and other high-priority forest conservation areas (Chesapeake Bay Program, 2018).

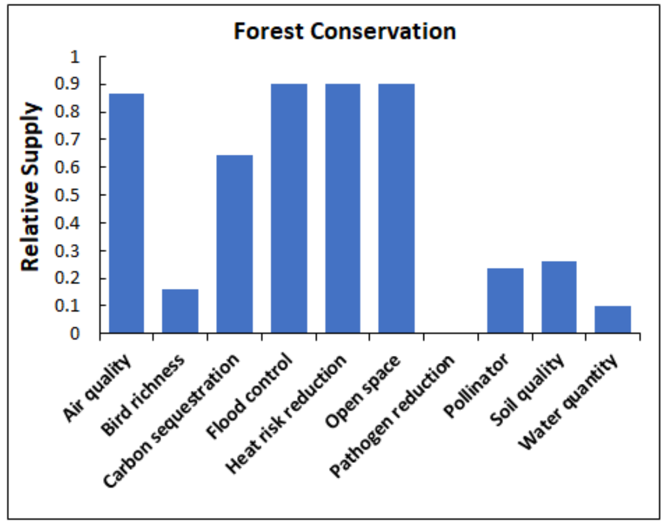


Figure 2.5.1. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by forest conservation relative to the minimum (0.1) and maximum (0.9) across all focal BMPs. Missing values are lack of data to quantify that service.

What are the additional benefits of forest conservation?

Forest conservation, and land preservation in general, is important to preserve habitats that may serve multiple purposes. Quantitative modeling (see Chapter 3) estimated forest conservation lands to be particularly important for providing shading to reduce heat risk, flood control, buffering air pollution, and for providing natural open space for habitat or recreational uses (Fig. 2.5.1).

In total, we identified 27 potential ecosystem services provided by forests that would benefit 33 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.5.2. For example, conserving large tracts of forest open space may provide recreation opportunities for people interested in experiences like hiking, hunting, and wildlife viewing.

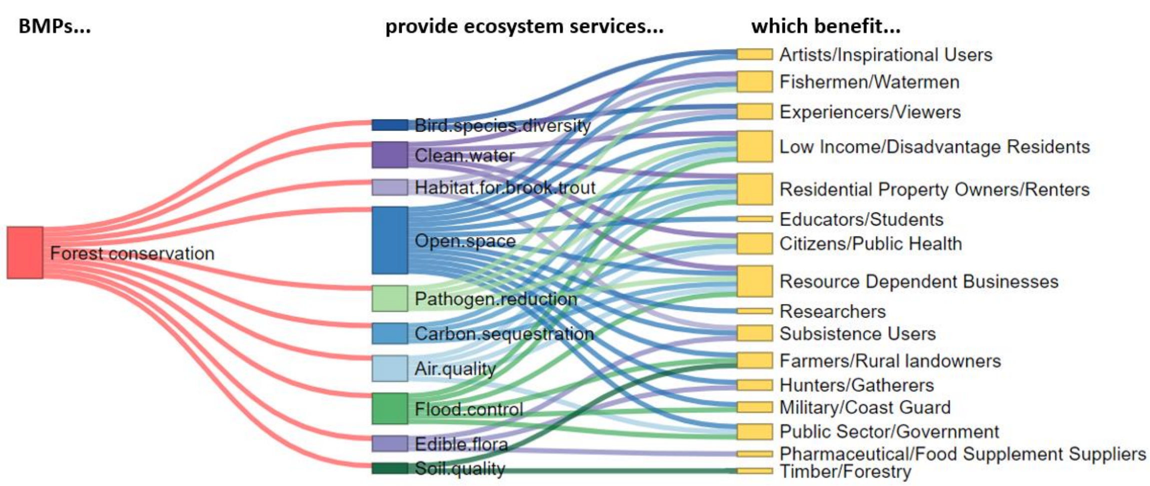


Figure 2.5.2. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from forest conservation?

We identified a direct connection between forest conservation and several Chesapeake Bay Watershed Agreement outcomes (Table 2.5.1). Outcomes are further described in **Chapter 4**.

Table 2.5.1. Connections between the forest conservation BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like forest conservation, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Forest conservation can help create black duck habitat.
Blue Crab Abundance	Forest conservation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Forest conservation can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through forest conservation can enhance resilience to flooding and coastal erosion.
Fish Habitat	Forest conservation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Forest Buffer	Acres of riparian forest buffers, and their capacity to provide water quality and habitat benefits, can be increased through forest conservation.
Healthy Watersheds	Forest conservation, by increasing trees and forests, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Forest conservation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through forest conservation ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through forest conservation allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing trees through forest conservation can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Forest conservation leads to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen, and traps the sediment that can reduce water clarity, allowing light to reach the SAV.
Tree Canopy Outcome	Forest conservation increases tree and forest canopy to provide air quality, water quality and habitat benefits if adjacent to urban areas.

Additional Resources

NRCS factsheet: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_025454.pdf

2.6. Grass Buffers

What is a grass buffer?

Grass buffers are linear strips of grass or other non-woody vegetation placed between the edge of a field and streams, rivers, or tidal waters to help filter nutrients, sediment and other pollutants from runoff. The recommended buffer width is 100 feet, with a 35 feet minimum width required. Grass buffers can be placed on agricultural or pasture land (Chesapeake Bay Program, 2018).

As of 2019, grass buffers were implemented at various acreages across the watershed with the largest implementation in Lancaster County, Pennsylvania (Fig. 2.6.1), based on county-level reporting data.

What are the additional benefits of implementing a grass buffer BMP?

Grass buffers help reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated grass buffers to be particularly important for reducing pathogen runoff, providing pollinator habitat, and for providing natural open space for habitat or recreational uses (Fig. 2.6.2).

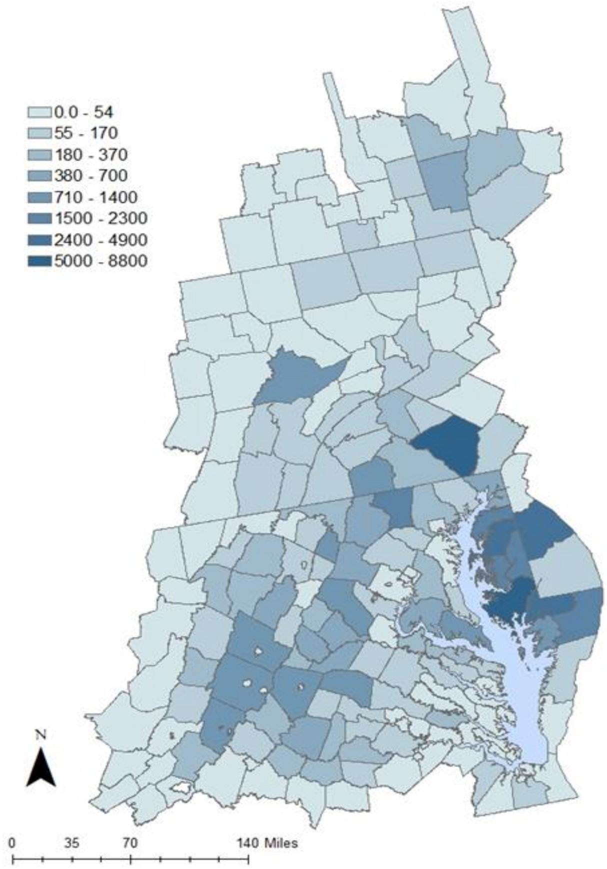


Figure 2.6.1. Cumulative acres of grass buffers (fenced and unfenced) implemented at the county level through 2019.

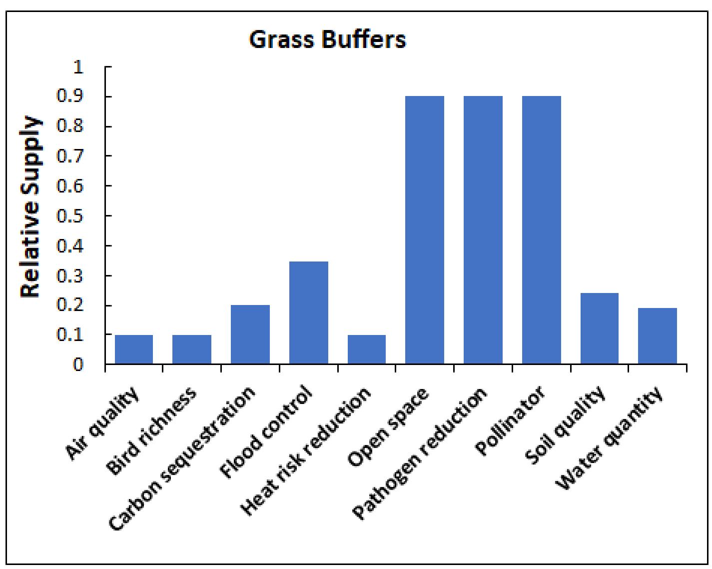


Figure 2.6.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by grass buffers relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 30 potential ecosystem services provided by grass buffer BMPs that would benefit 33 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.6.3. For example, grass buffers help with flood control by slowing runoff which benefits farmers and residents in the area. Grass buffers can also reduce pathogens from reaching waterways, which benefits farmers whose livestock use streams for water sources.

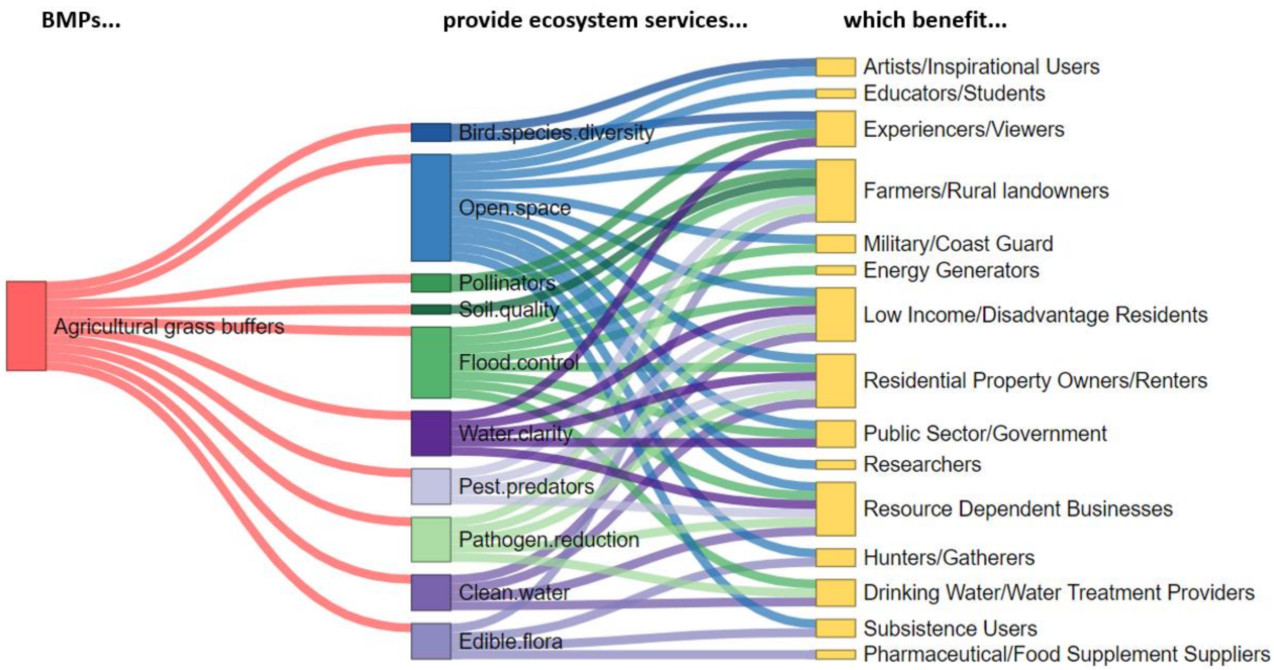


Figure 2.6.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from grass buffers?

We identified a direct connection between grass buffers and several Chesapeake Bay Watershed Agreement outcomes (Table 2.6.1). Outcomes are further described in Chapter 4.

Table 2.6.1. Connections between the grass buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like grass buffers, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Grass buffers can help create black duck habitat.
Blue Crab Abundance	Grass buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Grass buffers can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through grass buffers can enhance resilience to flooding and coastal erosion.

Fish Habitat	Grass buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Healthy Watersheds	Grass buffers help to maintain watersheds of high quality and high ecological value by providing critical ecosystem services like habitat and water filtration.
Oyster	Grass buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through creation of grass buffers ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through grass buffers allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing vegetation through grass buffers can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Grass buffers lead to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Wetlands	Grass buffers at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet:

https://www.chesapeakebay.net/documents/BMP-Guide_A.12_Forest-Buffers-and-Grass-Buffers_.pdf

NRCS BMP factsheets:

https://www.blogs.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcseprd1499250.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255021.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1241319.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255019.pdf

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263483.pdf

https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/FactSheets/archived-fact-sheets/practice_cp8a_grass_waterway_jul2015.pdf

2.7 Impervious Surface Reduction

What is Impervious surface reduction?

Impervious cover can either be physically removed (ICR; Impervious cover removal) or simply disconnected so that some portion of the runoff filters or infiltrates into adjacent pervious soils (ICD; Impervious cover disconnection). ICR in particular replaces impervious surfaces with pervious surfaces that have been de-compacted and amended to promote infiltration.

As of 2019, Fairfax County, Virginia has the greatest acreage of Impervious surface reduction BMP implemented (Fig. 2.7.1), based on county-level reporting data.

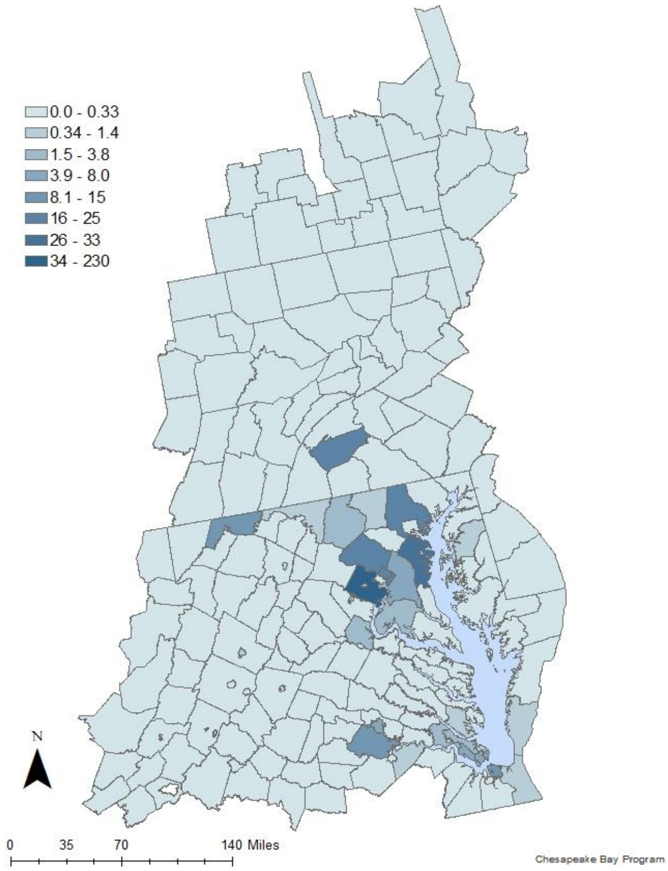


Figure 2.7.1. Cumulative acres of impervious surface reduction implemented at the county level through 2019.

What are the additional benefits of implementing the impervious surface reduction BMP?

Impervious surface reduction helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated impervious surface reductions to be particularly important for sequestering carbon, improving soil conditions, providing pollinator habitat, and providing natural open space for habitat or recreational uses (Fig. 2.7.2).

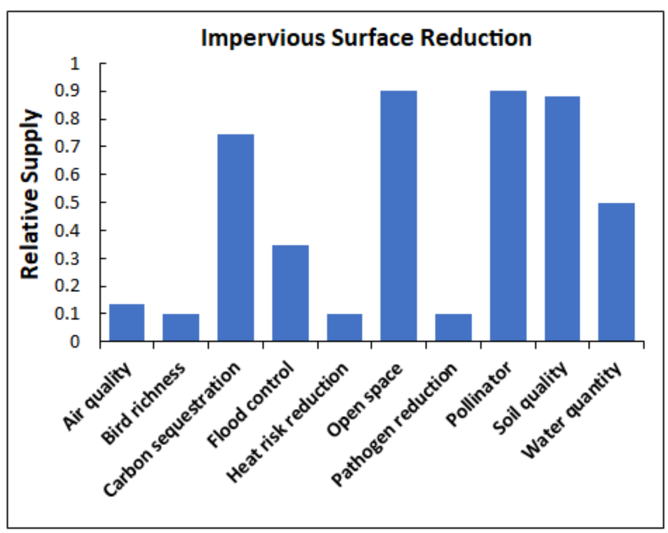


Figure 2.7.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by impervious surface reduction relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 19 potential ecosystem services provided by impervious surface reduction that would benefit 33 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.7.3. For example, impervious reduction may provide pathogen reduction which may benefit residents and local governments.

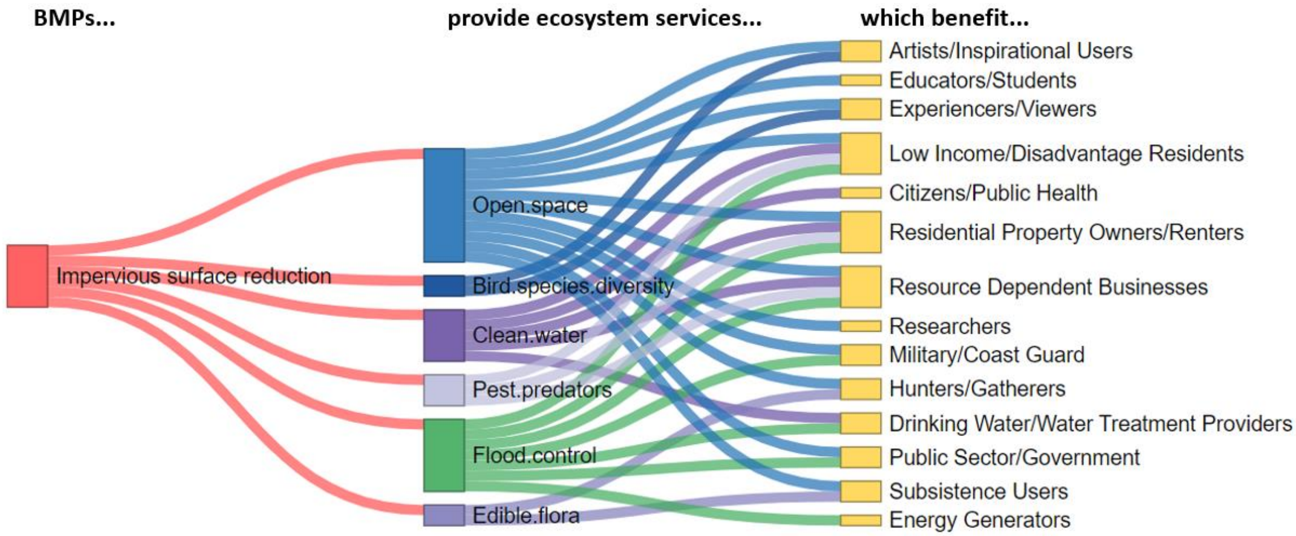


Figure 2.7.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from impervious surface reduction?

We identified a direct connection between impervious surface reduction and several Chesapeake Bay Watershed Agreement outcomes (Table 2.7.1). Outcomes are further described in Chapter 4.

Table 2.7.1. Connections between the agricultural forest buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like impervious surface reduction, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Blue Crab Abundance	Impervious surface reduction increases vegetation and soil infiltration that can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Impervious surface reduction increases vegetation that can help create cooler temperatures and healthy streams for fish.
Fish Habitat	Impervious surface reduction increases vegetation and soil infiltration that can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Healthy Watersheds	Impervious surface reduction, by increasing vegetation and soil infiltration, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.

Oyster	Impervious surface reduction increases vegetation and soil infiltration that can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Public Access Site Development	Ensuring access to natural lands by converting impervious surface to greenspace allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing vegetation and soil infiltration through impervious surface reduction can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Impervious surface reduction increases vegetation and soil infiltration that lead to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Impervious surface reduction increases vegetation and soil infiltration that can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet:
https://www.chesapeakebay.net/channel_files/40324/draft_impervious_cover_bmp_cleanup_memo_9.15.20.pdf

2.8. Urban Forest Buffers

What are urban forest buffers?

Forest buffers are linear wooded areas placed along the edge of streams, rivers, or tidal waters that help filter nutrients, sediment and other pollutants from runoff as well as remove nutrients from groundwater. The recommended buffer width is 100 feet, with a 35 feet minimum width required. Urban forest buffers must be planted in developed areas (Chesapeake Bay Program, 2018).

Implementation of urban forest buffers varies throughout the watershed with the highest implementation in Allegany County, Maryland, as of 2019 (Fig. 2.8.1), based on county-level reporting data.

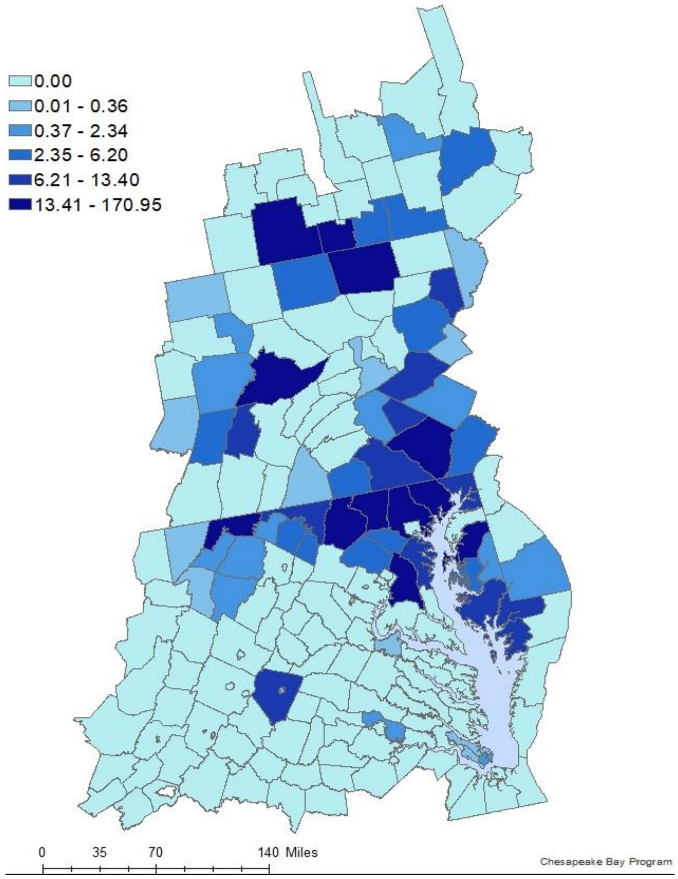


Figure 2.8.1. Cumulative acres of urban forest buffers implemented by county through 2019.

What are the additional benefits of implementing an urban forest buffer BMP?

Urban forest buffers help reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated forest buffers to be particularly important for providing shade to reduce heat risk, improving air quality, flood control, and for providing natural open space for habitat or recreational uses (Fig. 2.8.2).

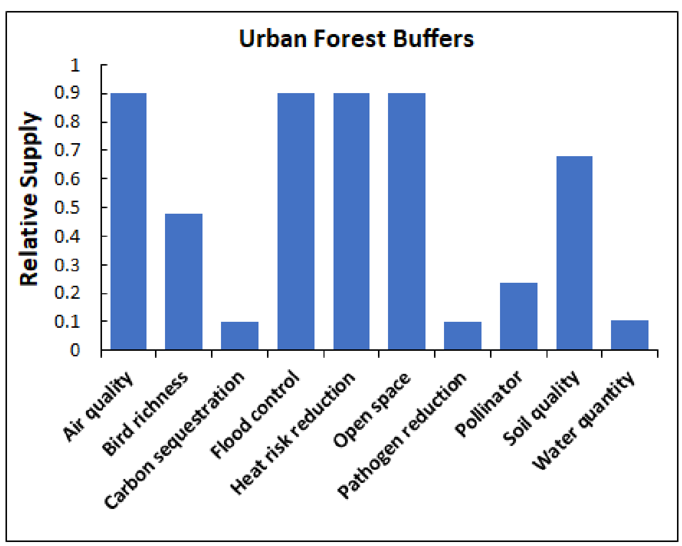


Figure 2.8.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by urban forest buffers relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 30 potential ecosystem services provided by urban forest buffer BMPs that would benefit 34 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.8.3. For example, forest buffers may provide green space for residents, educators and students, and wildlife viewers to enjoy.

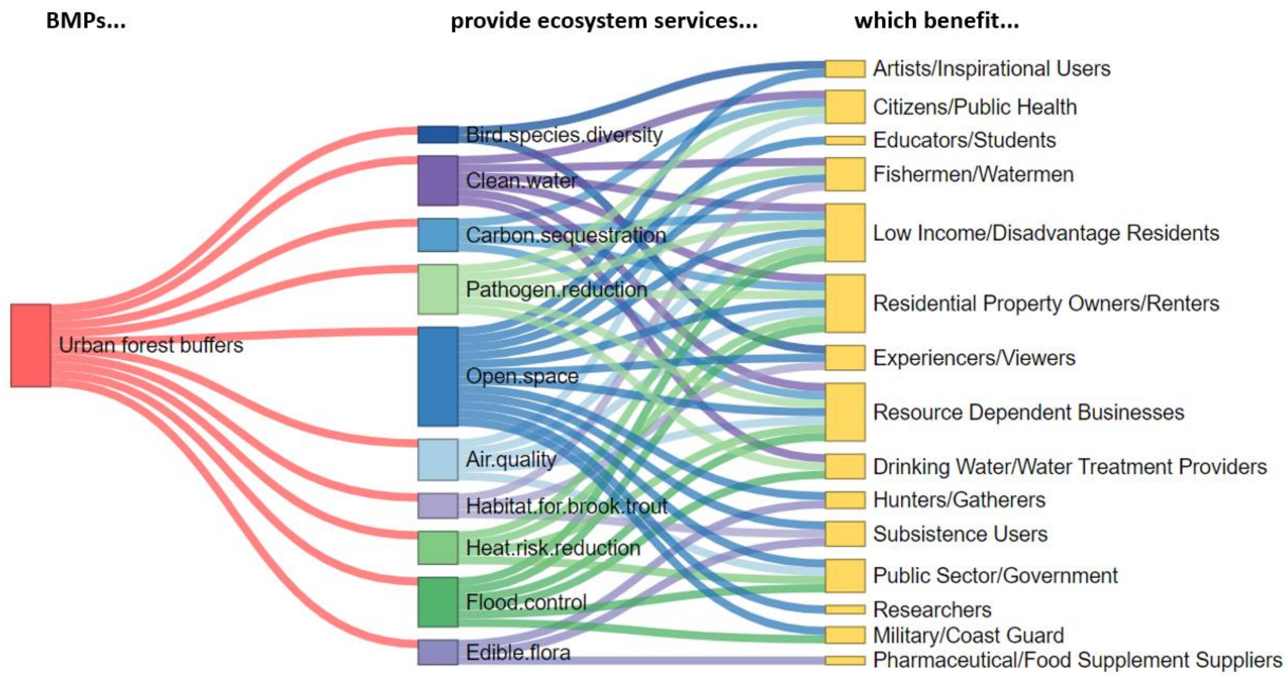


Figure 2.8.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from urban forest buffers?

We identified a direct connection between urban forest buffers and several Chesapeake Bay Watershed Agreement outcomes (Table 2.8.1). Outcomes are further described in Chapter 4.

Table 2.8.1. Connections between the agricultural forest buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like urban forest buffers, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Urban forest buffers can help create black duck habitat.
Blue Crab Abundance	Urban forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Urban forest buffers can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through urban forest buffers can enhance resilience to flooding and coastal erosion.

Fish Habitat	Urban forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Healthy Watersheds	Urban forest buffers, by increasing trees and forests, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Urban forest buffers can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through creation of urban forest buffers ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through urban forest buffers allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing trees and forest through urban forest buffers can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Urban forest buffers lead to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Urban forest buffers can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Tree Canopy Outcome	Urban forest buffers increase urban tree and forest canopy to provide air quality, water quality and habitat benefits in urban areas.
Wetlands	Urban forest buffers at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_D.7_Urban-Tree-Planting-BMPs_.pdf

2.9 Urban Forest Planting

What is urban forest planting?

Urban forest planting projects are in urban or suburban areas that are not specifically part of a riparian buffer (see Section 2.8), urban tree canopy (see Section 2.10), or structural BMP (e.g., tree planter) and must have the intent of establishing forest ecosystem processes and function. This requires urban forest plantings to be documented in a planting and maintenance plan that meets state planting density and associated standards for establishing forest conditions, including no fertilization and minimal mowing as needed to aid tree and understory establishment. Under this BMP, trees are planted in a contiguous area as documented in the planting plan, and the acreage of this BMP is converted from the developed turfgrass land use into forest in the modeling tools (Chesapeake Bay Program, 2018).

The highest implementation of urban forest planting, through 2019, was in Baltimore County, Maryland (Fig. 2.9.1), based on county-level reporting data.

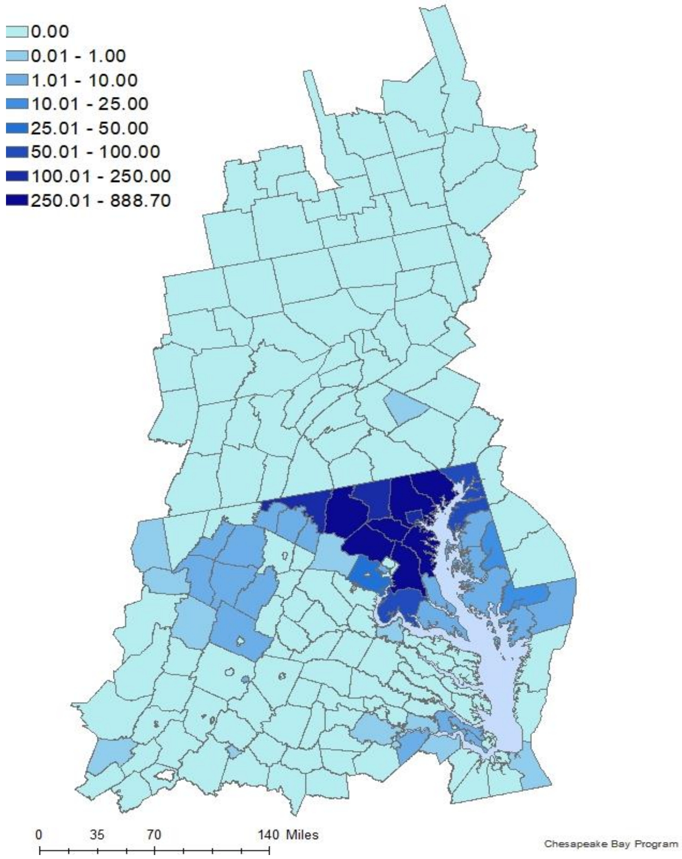


Figure 2.9.1. Cumulative acres of urban forest planting by county through 2019.

What are the additional benefits of implementing an urban forest planting BMP?

Urban forest planting helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated forest planting to be particularly important for providing shading to reduce heat risk, improving air quality by buffering pollutants, controlling flooding through rainwater retention, and for providing natural space for recreational or habitat or uses (Fig. 2.9.2).

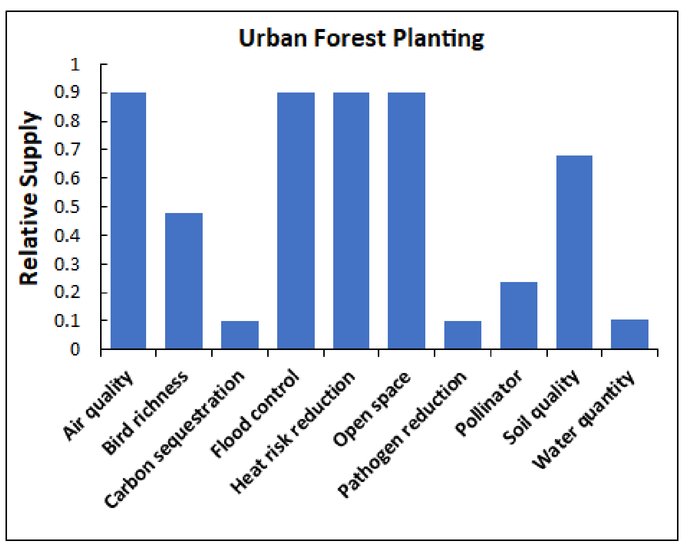


Figure 2.9.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by urban forest planting relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 30 potential ecosystem services provided by urban forest planting BMPs that would benefit 35 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.9.3. For example, planting an urban forest may help create shade and reduce air temperature during peak summer months which benefits residents and businesses nearby.

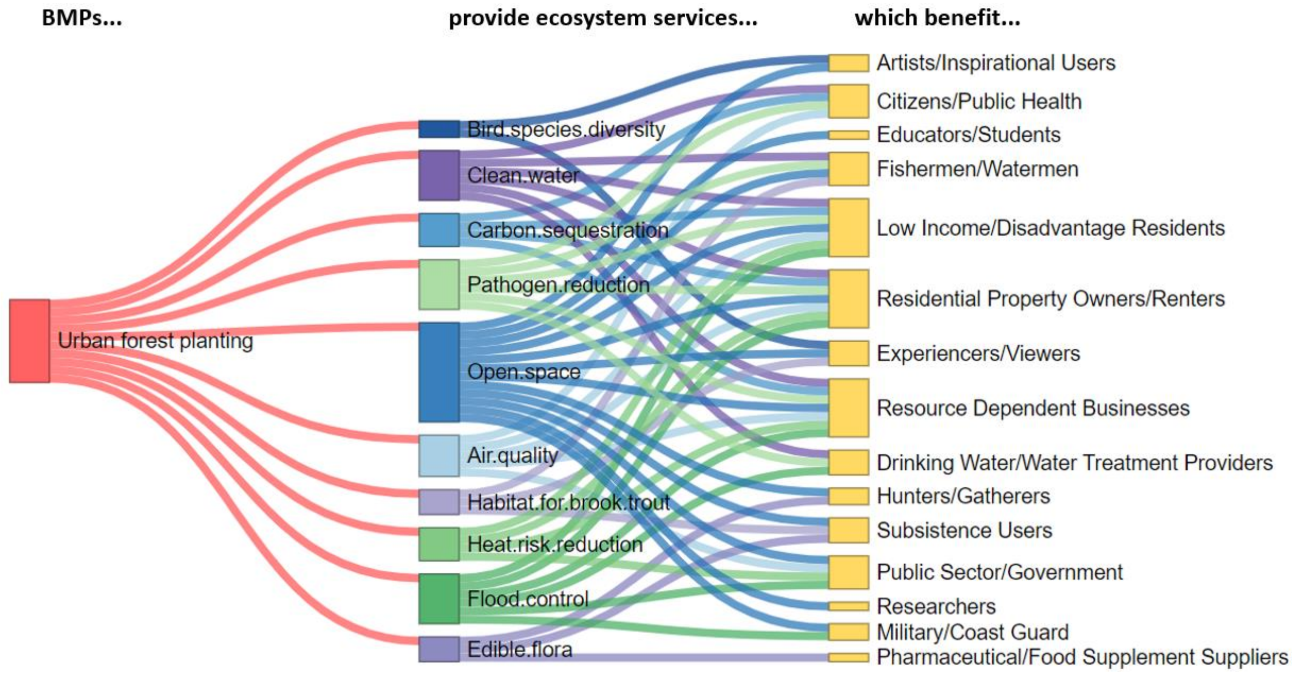


Figure 2.9.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from urban forest planting?

We identified a direct connection between urban forest planting and several Chesapeake Bay Watershed Agreement outcomes (Table 2.9.1). Outcomes are further described in Chapter 4.

Table 2.9.1. Connections between the agricultural forest buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like urban forest planting, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Urban forest planting can help create black duck habitat.
Blue Crab Abundance	Urban forest planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Urban forest planting can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through urban forest planting can enhance resilience to flooding and coastal erosion.

Fish Habitat	Urban forest planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Healthy Watersheds	Urban forest planting, by increasing trees and forests, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Urban forest planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through urban forest planting ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through urban forest planting allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing trees and forest through urban forest planting can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Urban forest planting leads to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Urban forest planting can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Tree Canopy Outcome	Urban forest planting increases urban tree and forest canopy to provide air quality, water quality and habitat benefits in urban areas.
Wetlands	Urban forest planting at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_D.7_Urban-Tree-Planting-BMPs_.pdf

2.10. Urban Tree Planting

What is urban tree planting?

The planting of trees in an urban area that are not part of a riparian forest buffer (see Section 2.8), urban forest planting (see Section 2.9), or a structural BMP (e.g., bioretention, tree planter). The land use area conversion factor is based on the panel's recommendation of 144 square foot average of canopy per tree planted. Thus, 300 newly planted trees are equivalent to one acre of tree canopy land use; however, this is not a planting density requirement, and each tree converts 1/300 of an acre of either pervious or impervious developed area to tree canopy land uses. This BMP does not require trees to be planted in a contiguous area (Chesapeake Bay Program, 2018).

As of 2019, Howard County, Maryland had the most acres of urban tree planting in the watershed (Fig. 2.10.1), based on county-level reporting data.

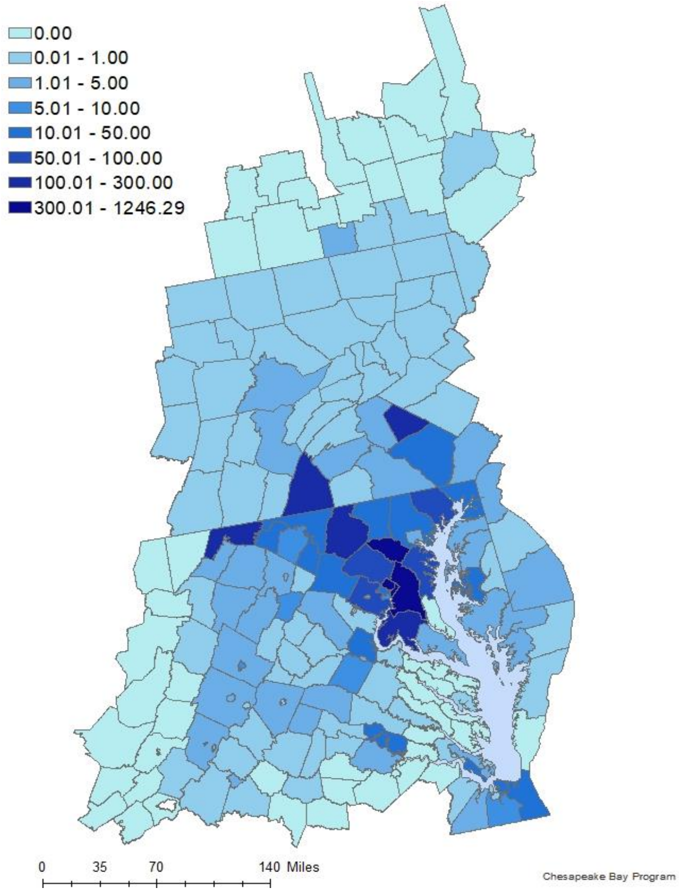


Figure 2.10.1. Cumulative acres of urban tree planting by county through 2019.

What are the additional benefits of implementing an urban tree planting BMP?

Urban tree planting helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see Chapter 3) estimated urban tree planting to be particularly important for providing shading to reduce heat risk, improving air quality by buffering pollutants, maintaining water availability and flow, and for providing natural open space for habitat or recreational uses (Fig. 2.10.2).

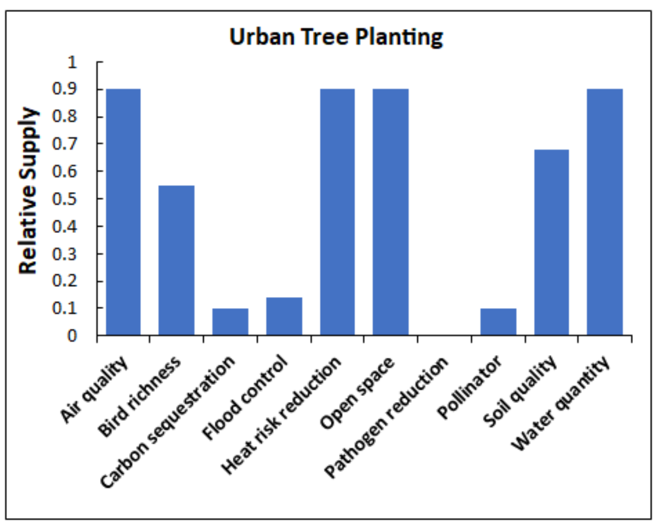


Figure 2.10.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by urban tree planting relative to the minimum (0.1) and maximum (0.9) across all focal BMPs. Missing values are due to lack of data to quantify that particular service.

In total, we identified 21 potential ecosystem services provided by Urban Tree Planting BMPs that would benefit 27 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.10.3. For example, urban tree planting may provide shade which helps reduce air temperatures during extreme heat which benefits residents and businesses.

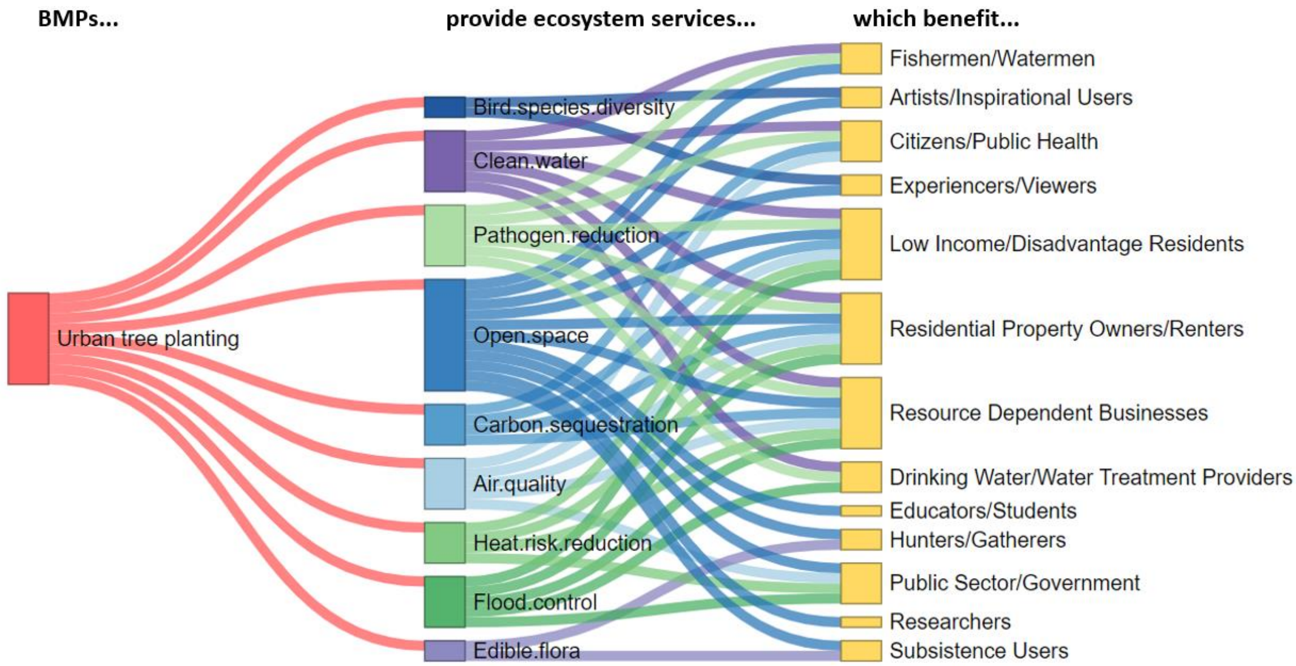


Figure 2.10.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from urban tree planting?

We identified a direct connection between urban tree planting and several Chesapeake Bay Watershed Agreement outcomes (Table 2.10.1). Outcomes are further described in Chapter 4.

Table 2.10.1. Connections between agricultural forest buffer BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like urban tree planting, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Urban tree planting can help create black duck habitat.
Blue Crab Abundance	Urban tree planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Urban tree planting can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through urban tree planting can enhance resilience to flooding and coastal erosion.

Fish Habitat	Urban tree planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Forest Buffer	Acres of riparian forest buffers, and their capacity to provide water quality and habitat benefits, can be increased through urban tree planting.
Healthy Watersheds	Urban tree planting, by increasing trees and forests, help to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Urban tree planting can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through urban tree planting ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through urban tree planting allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Increasing trees and forest through urban tree planting can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Toxic Contaminants Policy & Prevention	Urban tree planting can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Tree Canopy Outcome	Urban tree planting increases urban tree and forest canopy to provide air quality, water quality and habitat benefits in urban areas.
Wetlands	Urban tree planting at the edge of wetlands can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_D.7_Urban-Tree-Planting-BMPs_.pdf

2.11. Wetland Creation

What is wetland creation?

Wetland creation is the manipulation of the physical, chemical, or biological characteristics present to develop a wetland that did not previously exist at a site. Wetland creation can be done in tidal and non-tidal wetland areas, but here we focus on nontidal wetland areas (Chesapeake Bay Program, 2018).

The maximum acres of wetland creation implemented in the watershed, as of 2019, was about 330 acres in Queen Anne's County, Maryland (Fig. 2.11.1), based on county-level reporting data.

What are the additional benefits of implementing a wetland creation BMP?

Wetland creation helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see [Chapter 3]) estimated wetland creation to be particularly important for supporting bird biodiversity, carbon sequestration, quality soils, and open space for habitat or recreational uses (Fig. 2.11.2).

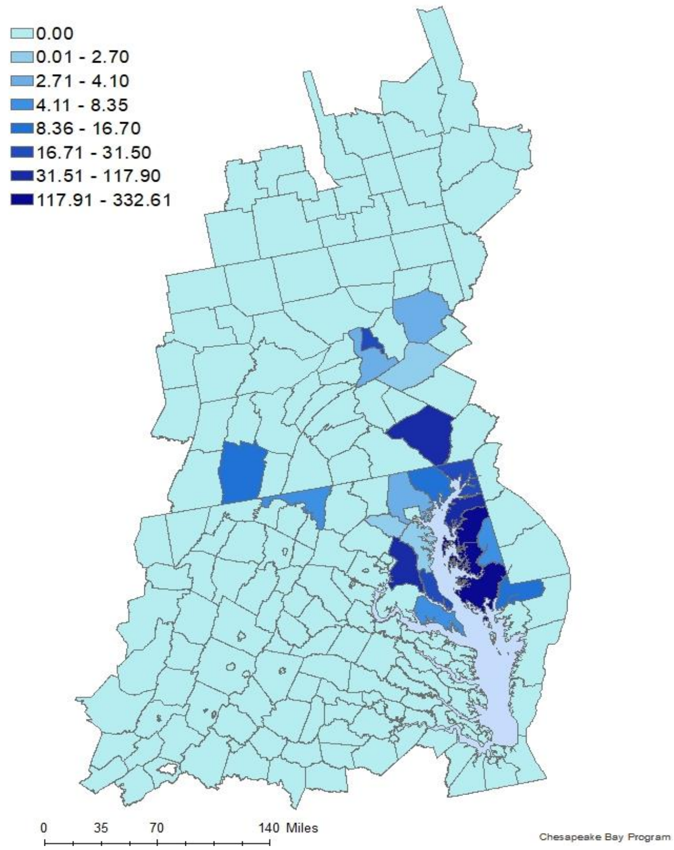


Figure 2.11.1. Cumulative acres of wetland creation by county through 2019.

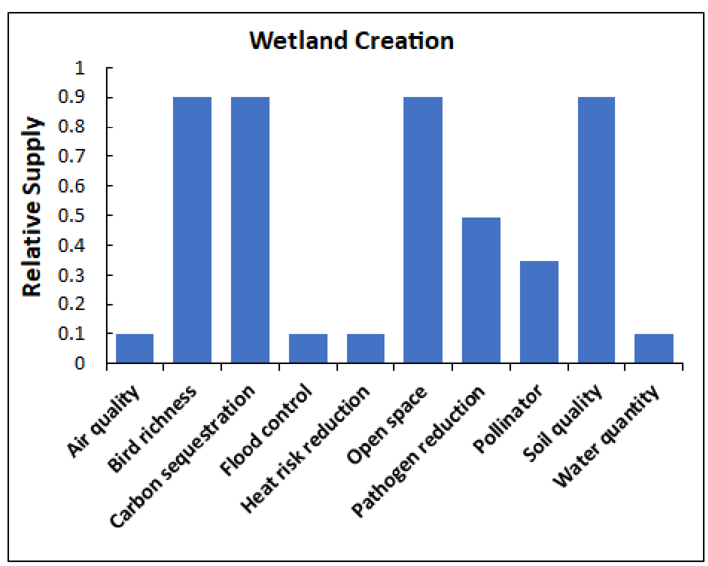


Figure 2.11.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by wetland creation relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 34 potential ecosystem services provided by wetland creation that would benefit 43 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.11.3. For example, creating a wetland may provide flood control which would benefit nearby residents, farms, and businesses.

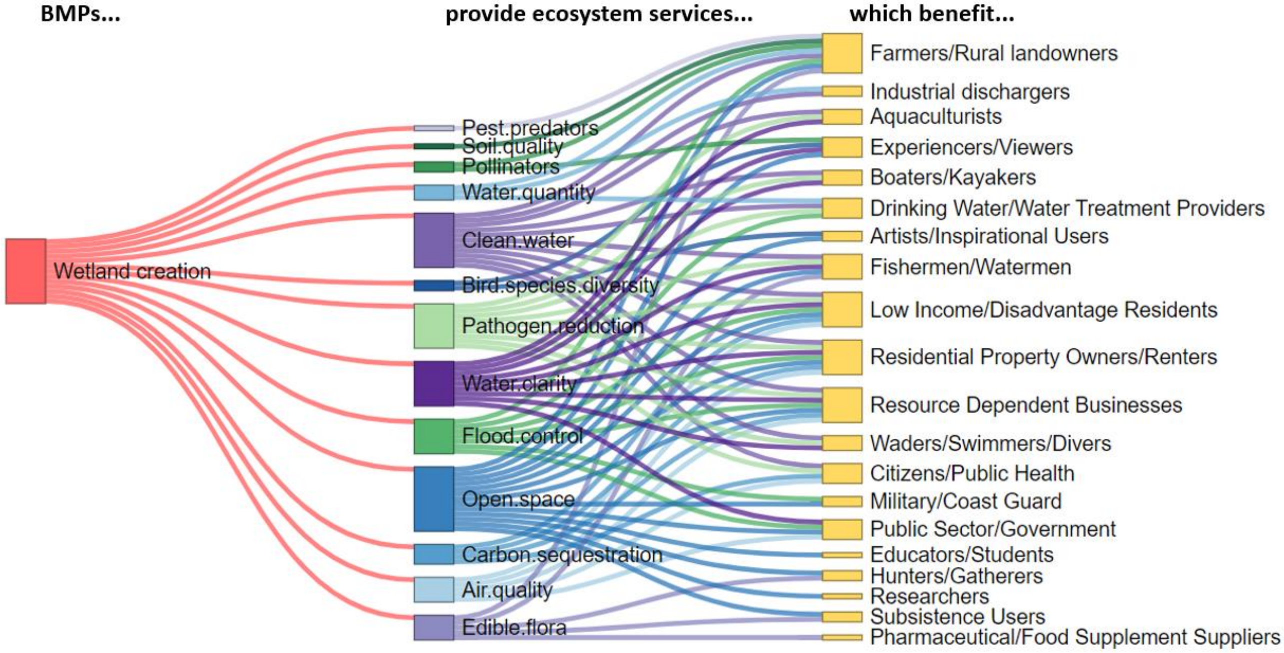


Figure 2.11.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from wetland creation?

We identified a direct connection between wetland creation and several Chesapeake Bay Watershed Agreement outcomes (Table 2.11.1). Outcomes are further described in Chapter 4.

Table 2.11.1. Connections between the wetland creation BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like wetland creation, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Wetland creation can help create black duck habitat.
Blue Crab Abundance	Wetland creation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Wetland creation can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through wetland creation can enhance resilience to flooding and coastal erosion.

Fish Habitat	Wetland creation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Forest Buffer	Acres of riparian forest, and their capacity to provide water quality and habitat benefits, can be increased through forested wetland creation.
Healthy Watersheds	Wetland creation helps to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Wetland creation can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through wetland creation ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through wetland creation allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Wetland creation can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Wetland creation leads to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Wetland creation can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Tree Canopy Outcome	Forested wetland creation increases urban tree and forest canopy to provide air quality, water quality and habitat benefits if adjacent to urban areas.
Wetlands	Wetland creation can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_A.25_Wetland-Restoration_.pdf

NRCS factsheet: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255219.pdf

2.12. Wetland Restoration

What is wetland restoration?

Wetland restoration is the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former wetland. Wetland restoration can occur in tidal and non-tidal wetland areas, but here we focus on nontidal wetland areas (Chesapeake Bay Program, 2018).

Implementation through 2019 was close to zero for most of the watershed with the greatest amount implemented in Kent County, Delaware (Fig. 2.12.1), based on county-level reporting data.

What are the additional benefits of implementing a wetland restoration BMP?

Wetland restoration helps reduce nitrogen, phosphorous, and sediment loads while also providing additional ecosystem services. Quantitative modeling (see **Chapter 3**) estimated wetland restoration to be particularly important for supporting bird biodiversity, carbon sequestration, quality soils, and open space for habitat or recreational uses (Fig. 2.12.2).

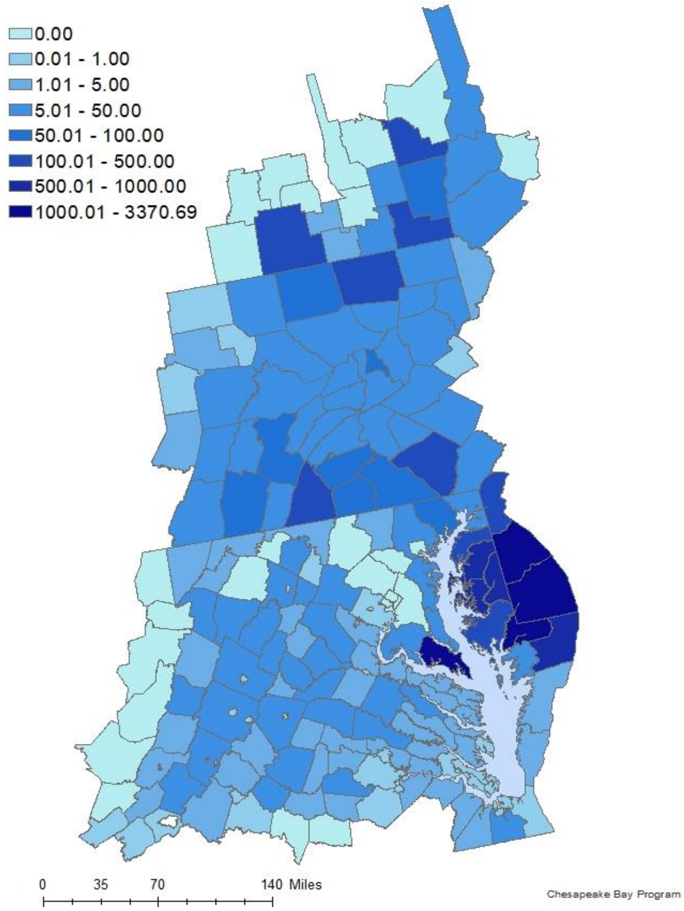


Figure 2.12.1. Cumulative acres of wetland restoration implemented by county through 2019.

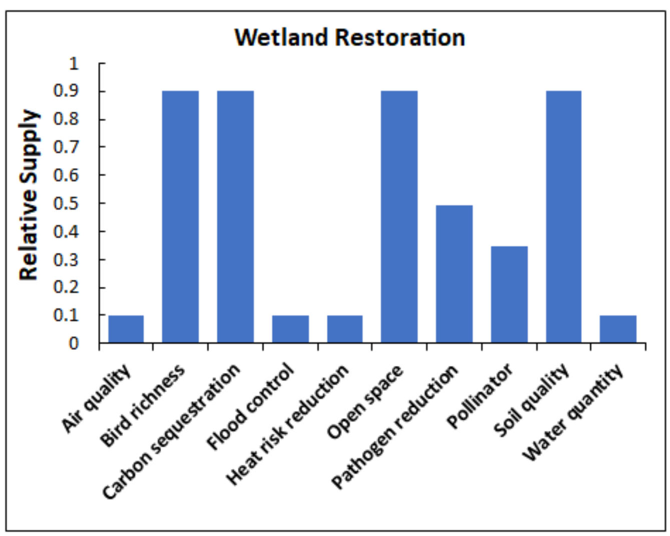


Figure 2.12.2. Relative supply of ecosystem services, each scaled from 0.1 to 0.9 to indicate supply by wetland restoration relative to the minimum (0.1) and maximum (0.9) across all focal BMPs.

In total, we identified 34 potential ecosystem services provided by wetland restoration that would benefit 43 potential user groups (Rossi et al., 2022a), some of which are illustrated in Fig. 2.12.3. For example, restoring a wetland may provide flood control which would benefit nearby residents, and public property owners.

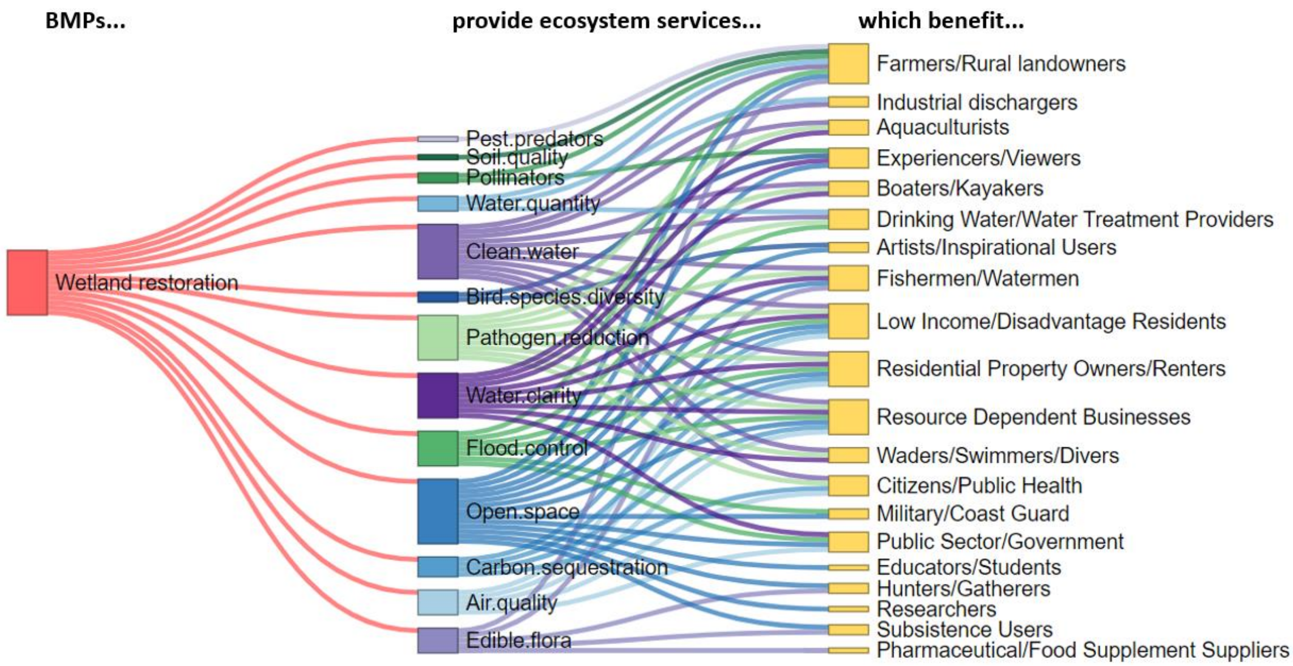


Figure 2.12.3. Diagram of user groups (yellow boxes, right) most likely to benefit from priority ecosystem services (blue/green/purple boxes, center) identified through initial scoping and prioritization efforts (see Rossi et al. 2022a) if this BMP is implemented (red box, left). Some priority ecosystem services (purple boxes) were not quantified as part of this report (see Appendix A12). The full suite of potential ecosystem services benefits and beneficiaries associated with each BMP is available in Rossi et al. 2022a.

What watershed outcomes may benefit from wetland restoration?

We identified a direct connection between wetland restoration and several Chesapeake Bay Watershed Agreement outcomes (Table 2.12.1). Outcomes are further described in Chapter 4.

Table 2.12.1. Connections between the wetland restoration BMP and Watershed Agreement outcomes.

OUTCOME	RELATIONSHIP
2025 WIP	The WIPs include management practices, like wetland restoration, expected to reduce nitrogen, phosphorus, and sediment in local waters and in the Chesapeake Bay.
Black Duck	Wetland restoration can help create black duck habitat.
Blue Crab Abundance	Wetland restoration can help reduce nitrogen and phosphorus runoff that make waters unhealthy for crabs.
Brook Trout	Wetland restoration can help create cooler temperatures and healthy streams for fish.
Climate Adaptation	Creating natural lands through wetland restoration can enhance resilience to flooding and coastal erosion.

Fish Habitat	Wetland restoration can help reduce nitrogen and phosphorus runoff that make waters unhealthy for fish.
Forest Buffer	Acres of riparian forest, and their capacity to provide water quality and habitat benefits, can be increased through forested wetland restoration.
Healthy Watersheds	Wetland restoration helps to maintain watersheds of high quality and high ecological value, which provide critical ecosystem services like habitat and clean water.
Oyster	Wetland restoration can help reduce nitrogen and phosphorus runoff that make waters unhealthy for oysters.
Protected Lands	Protecting lands in permanent easements and other natural lands preservation programs through wetland restoration ensures that natural landscapes will persist for future generations.
Public Access Site Development	Ensuring access to natural lands through wetland restoration allows humans to enjoy the beauty and peace of natural landscapes and water.
Stream Health	Wetland restoration can reduce temperatures in streams, filter nutrient and sediment runoff, and maintain stable flow.
Submerged Aquatic Vegetation (SAV)	Wetland restoration leads to reduced nitrogen and phosphorus runoff that leads to low amounts of dissolved oxygen. They also trap the sediment that can reduce water clarity, allowing light to reach the SAV.
Toxic Contaminants Policy & Prevention	Wetland restoration can trap toxic contaminants before they reach our waterways ensures we have clean water for drinking and the ecosystem.
Tree Canopy Outcome	Forested wetland restoration increases urban tree and forest canopy to provide air quality, water quality and habitat benefits if adjacent to urban areas.
Wetlands	Wetland restoration can help to maintain and increase the capacity of wetlands to provide habitat and water quality benefits throughout the watershed.

Additional Resources

Chesapeake Bay Program BMP Guide factsheet: https://www.chesapeakebay.net/documents/BMP-Guide_A.25_Wetland-Restoration_.pdf

NRCS factsheet: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1255218.pdf

Chapter 3. Ecosystem Services

3.1. What are Final Ecosystem Goods and Services?

Ecosystem services are “the benefits humans obtain from ecosystems that support (directly or indirectly) their survival and quality of life” (Millenium Ecosystem Assessment, 2005). Intermediate ecosystem services such as water or habitat quality may be impacted by management actions, but they may not resonate with local stakeholders because they are not directly connected to or used by stakeholders (Boyd et al., 2015). To connect to stakeholders more directly, we use the concept of Final Ecosystem Goods and Services (FEGS). FEGS are “outputs from nature that are directly used or appreciated by humans in diverse ways” (Newcomer-Johnson et al., 2021). Each FEGS comprise three components: 1) the beneficiary or user that cares about or uses them, 2) the biophysical attributes that beneficiaries or users cares about, and 3) the ecosystem producing the biophysical attributes that provide the good or service. For example, minimal levels of pathogens in coastal waters used by swimmers or anglers.

3.1.1. How did we arrive at our short list of FEGS?

To arrive at a short list of ecosystem services for quantitative assessment, we first generated a long list of potential FEGS provided by each BMP. The initial list was developed using the National Ecosystem Services Classification System (NESCS Plus) to identify beneficiary groups and ecosystem services attributes for each BMP habitat, which was refined and supplemented by reviewing existing relevant documents from the CBP (Newcomer-Johnson et al., 2021). To scope the long list of potential FEGS to a short list of 10-15 FEGS, we solicited CBP partner feedback to help identify priority FEGS and we also used a decision support tool, The Final Ecosystem Goods and Services Scoping Tool (FEGS Scoping Tool), to help prioritize (Rossi et al., 2022a; Sharpe et al., 2020). Below we outline a summary of our prioritization steps but for more details see Rossi et al. (2022).

We used the FEGS Scoping Tool to help prioritize ecosystem services for further analysis using CBP partner feedback and information gleaned from document analysis. We weighted FEGS identified by partner feedback and/or from CBP documents more than other FEGS (such as those from NESCS Plus) to generate a list of priority FEGS. In our feedback from partners, there were multiple specific comments about ensuring that user groups such as farmers and underrepresented communities would benefit from the final set of prioritized FEGS. To account for these comments, we again used the FEGS Scoping Tool and weighted any FEGS that would be directly used by a farmer and/or someone in an underrepresented community more than other FEGS. We compared the prioritized lists from the FEGS Scoping Tool and narrowed the final FEGS to the following: air quality, bird species, clean water*[1], edible flora*[2], flood control, green space, heat risk, pathogen reduction, pest predator supply*[3], pollinator supply, soil quality, water clarity*[4], and water quantity.

[1] Clean water was not quantified since CAST provides estimates of nutrient reductions for BMPs already. See Appendix A12 for more details.
[2] Edible flora was not quantified because we could not find adequate data on species planted in forest and grass buffer BMPs to estimate this. See Appendix A12 for more details.
[3] Pest predator supply was not quantified due to lack of sufficient data on species of interest. See Appendix A12 for more details.
[4] Water clarity was not quantified due to insufficient data. See Appendix A12 for more details.

We presented this list to partners for one last round of feedback and ultimately added carbon sequestration because partners were very interested in beginning to quantify carbon sequestration for management practices.

3.1.2. Quantifying Measures of FEGS

Once priority FEGS have been identified, the next step is to identify a metric (or set of metrics) that may be modeled, measured, or monitored to quantify each ecosystem service. For each priority ecosystem service, we identified candidate metrics based on the availability of data and models to be able to translate information on biological condition (i.e., acres of BMP implementation) into potential supply of ecosystem services (Rossi et al., 2022a). These models, known as ecological production functions (Bruins et al., 2017), can range from fairly simple lookup tables to statistical models to complex biophysical models. Recent examples have used such models to translate maps of land cover into ecosystem services in Florida (Russell et al., 2013) and Puerto Rico (Smith et al., 2020).

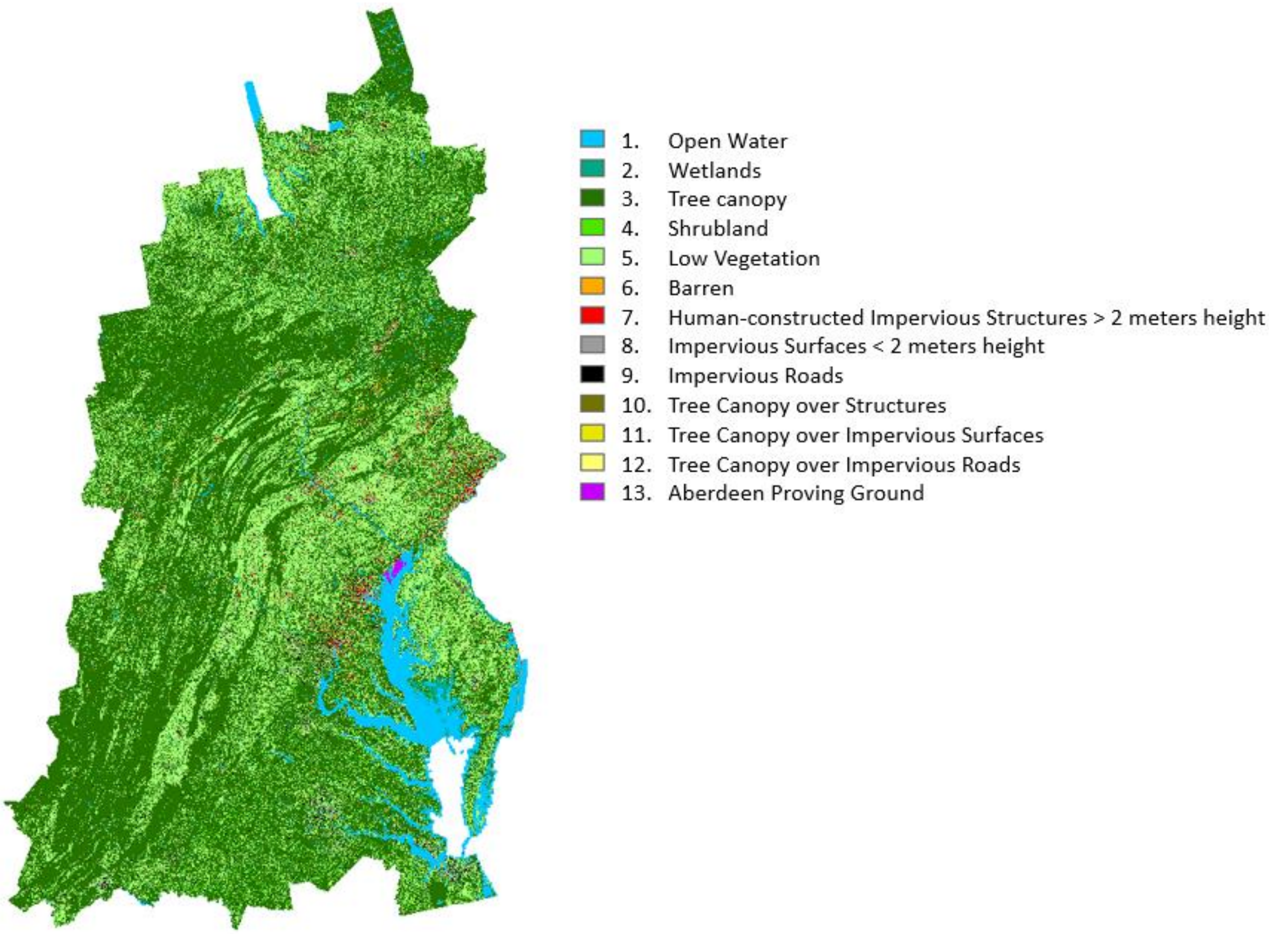


Figure 3.1.1. 2013/2014 land use land cover data in CAST.

To maintain compatibility with tools used by Chesapeake Bay Program and their partners, we based our ecosystem services analysis on the Chesapeake Bay Conservancy 1 meter resolution 2013/2014 land use land cover maps used with the Chesapeake Bay Assessment Scenario Tool (CAST; https://cast.chesapeakebay.net/) (Fig. 3.1.1).

In general, we assumed each of our target BMPs would result in new acres of a landcover, such as natural tree canopy or wetland (see **Appendix A1** for more details). We then reviewed literature to assemble average values of FEGS supply by landcover type, reviewing existing models to translate landcover into FEGS supply or using available data to generate statistical relationships between known acres of landcover and observed measures of ecosystem services. This kind of landcover-based approach allows compatibility with landcover-based tools or assessments, we note that ultimately ecosystem services provisioning by the BMP will depend on i) what the BMP acres are replacing, for example if the BMP replaces a habitat that is comparable or even better at providing a particular ecosystem service, ii) finer details of landcover not captured by the existing categories, such as the species of cover crop, and iii) the quality or condition of the BMP habitat, such as the density, diversity, or maturity of tree planting. Ecosystem services estimates can be refined over time as more detailed information becomes available.

3.1.3. FEGS fact sheet overview

For each of the assessed ecosystem services, we have created a fact sheet that contains the following information:

- Why that FEGS matters
- Who is impacted by that FEGS
- Current estimate of that FEGS by county
- How the FEGS is quantified
- Data limitations
- How to use the information
- What BMPs (described in **Chapter 2**) provide the FEGS
- Examples of Watershed Agreement outcomes (described in **Chapter 4**) that may also increase FEGS provisioning or that may benefit from actions to improve FEGS

Further details on how each ecosystem service was quantified are provided in **Appendix A**.

3.2. Air Quality

Why is air quality important?

Air quality can impact human health and ecosystem health.

Who is impacted by air quality?

There are many beneficiaries, or users of an ecosystem, that benefit from the final ecosystem service of air quality. All humans, public sector property owners, residents who own property, residents who rent, residents in low income or disadvantaged areas, and resource dependent businesses are examples of beneficiaries.

How do we quantify the ability of ecosystems to improve air quality?

There are many variables that can impact air quality including concentration of pollutants in the air, pollen, air temperature, and weather patterns. We have chosen to focus on pollutants such as CO, SO_2, NO_2, O_3, $PM_{2.5}$, PM_{10} and quantify how tree cover contributes to air pollutant removal using methods developed by iTree (https://www.itreetools.org/). Briefly, we used multipliers of air pollutant removal rates developed by iTree and multiplied by tree cover to determine air pollutant removal potential for each of the six pollutants (Appendix A2). Tree cover was determined for each county using the Chesapeake Bay Conservancy 2013/2014 1 meter land use landcover dataset. Counties throughout the watershed had different levels of air pollutant removal depending on tree canopy cover (Fig. 3.2.1).

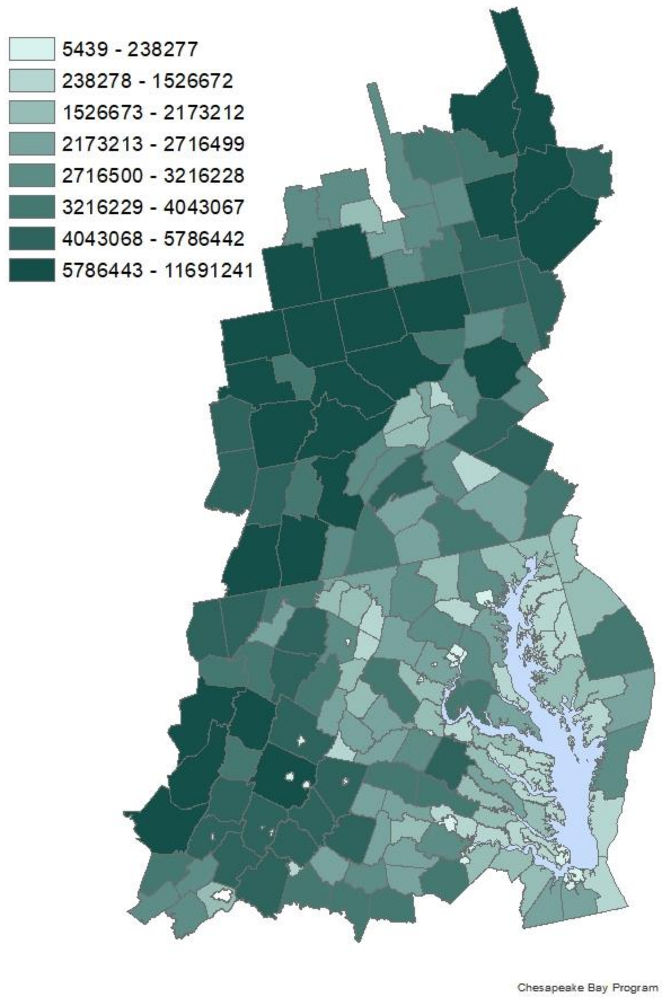


Figure 3.2.1. Current air pollutant removal potential of PM_{10} by county within Chesapeake Bay Watershed. Counties with lower removal potential may want to take actions to increase tree cover.

Limitations

This method is based on iTree methods that were developed for the entire United States, as a result, we are using averages from the entire US to provide pollutant removal estimates.

How can this information be used?

The current pollutant removal rate estimates can be used to determine where in the watershed to consider planting more trees to aid with pollutant removal.

What Watershed Agreement outcomes may benefit from actions to improve air quality?

Implementation of restoration and conservation related BMPs with a primary goal of improving air quality may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to improve air quality
- Stream health – continually improve stream health and function, such as by reducing atmospheric deposition
- Healthy watersheds – current healthy watersheds and waters remain healthy, including the air
- Public access development – public access opportunities for boating, swimming, fishing, such as where air is clean and safe for human activity

What Watershed Agreement outcomes may help improve air quality?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to air quality:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including the ability to buffer and filter air pollutants
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including the ability to buffer and filter air pollutants
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including the ability to buffer and filter air pollutants
- Protected lands – protect lands identified as high conservation priorities, including wetlands and forests that help to filter air pollutants
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits for improving air quality

What best management practices (BMPs) may help improve air quality?

BMPs that increase tree cover are especially important in improving air quality because trees can capture pollutants in the air. For BMPs implemented on agricultural lands, a rural multiplier is used (see Appendix A2 for details). For BMPs implemented on urban lands, an urban multiplier is used. Once we determined which multiplier to use, we simply multiplied the number of acres of a BMP times the correct multiplier. Table 3.2.1 and Figure 3.2.2 below shows estimates for different pollutant removals based on 20 acres of a BMP implemented. Units are lb/acre/yr.

Table 3.2.1. Rates of air pollutant removal (lb/acre/yr) for each BMP.

BMP	CO	O_3	SO_2	NO_2	$PM_{2.5}$	PM_{10}
AG FOREST BUFFER	17.86	981.05	61.97	97.34	47.51	330.59
AG TREE PLANTING	17.86	981.05	61.97	97.34	47.51	330.59
COVER CROPS	---	433.6	24.98	44.61	5.35	---
FOREST CONSERVATION	17.86	981.05	61.97	97.34	47.51	330.59
GRASS BUFFER	---	433.6	24.98	44.61	5.35	---

IMPERVIOUS SURFACE REDUCTION	---	522.82	28.55	64.24	7.14	---
URBAN FOREST BUFFER	22.68	965.15	61.44	125.02	49.29	273.97
URBAN FOREST PLANTING	22.68	965.15	61.44	125.02	49.29	273.97
URBAN TREE PLANTING	22.68	965.15	61.44	125.02	49.29	273.97
WETLAND CREATION	---	433.6	24.98	44.61	5.35	---
WETLAND RESTORATION	---	433.6	24.98	44.61	5.35	---

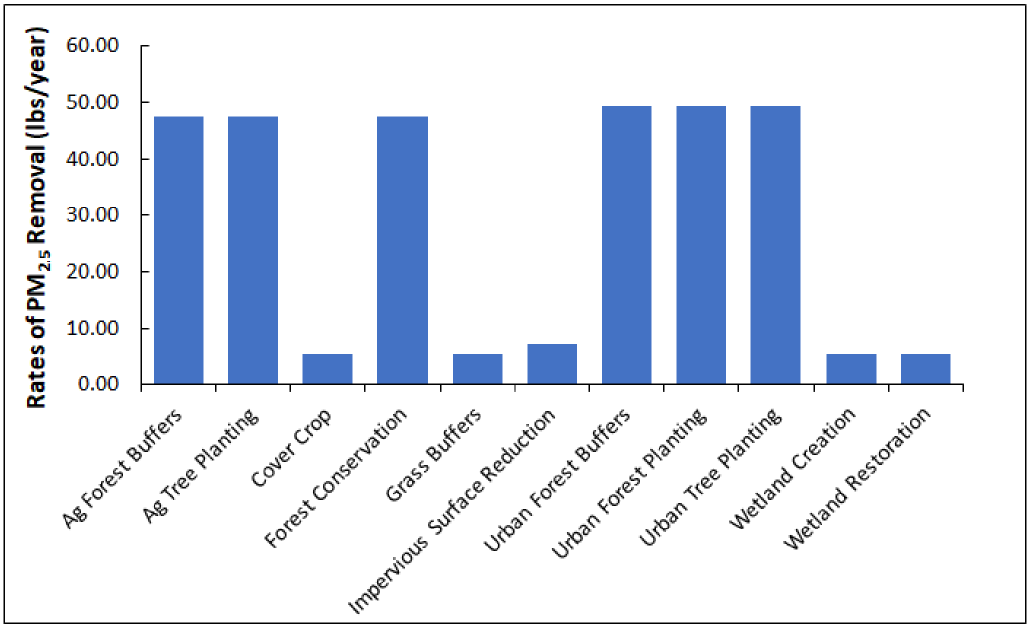


Figure 3.2.2. Air pollutant removal of $PM_{2.5}$ for 20 acres of different BMPs.

Additional Resources

iTree: https://www.itreetools.org/

Gopalakrishnan, V., S. Hirabayashi, G. Ziv, and B. R. Bakshi. 2018. Air quality and human health impacts of grasslands and shrublands in the United States. Atmospheric Environment 182:193-199.

3.3. Bird Species Diversity

Why are bird species important as an ecosystem service?

Many people enjoy birdwatching, especially for some of the more well known, or large birds. Additionally, the presence or absence of bird species may be a useful indicator for habitat quality.

Who is impacted by bird species?

There are many beneficiaries, or users of an ecosystem, that benefit from birds. Some beneficiaries to consider are artists, experiencers and viewers (e.g., birdwatchers), hunters, farmers, subsistence users of food and medicinal flora or fauna, and resource dependent businesses.

How do we quantify bird species?

For bird species, we have chosen to use bird species richness (number of bird species). Briefly, we used species area curves to determine the relationship between habitat area and bird species richness for every different land use in the watershed. Then we used each curve to estimate how many bird species may be in a certain area of each land use (Appendix A3). Counties throughout the watershed had different levels of bird species richness depending on land cover (Fig. 3.3.1).

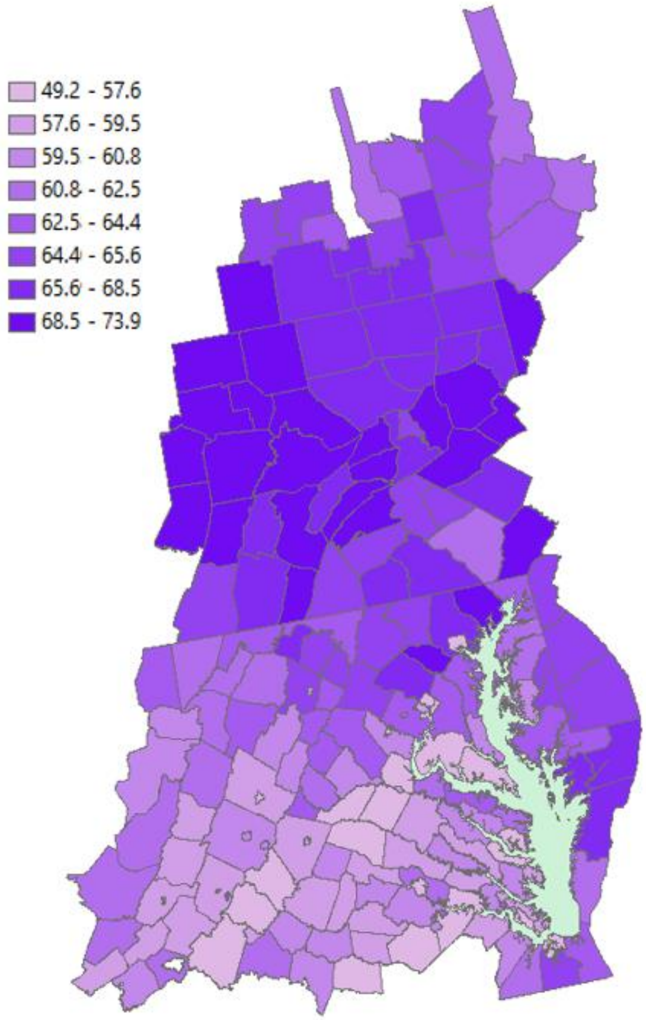


Figure 3.3.1. Estimated number of bird species in each county in Chesapeake Bay Watershed based on USGS GAP data.

Limitations

USGS GAP species richness data is based on modeling predicted habitat which includes habitat that may be used for breeding, overwintering, or year-round use. It is not based on wildlife counts.

How can this information be used?

Users can explore the current estimate of bird species richness for their county and then explore the relationships between different land uses and bird species richness to determine if there are certain land uses that can be restored or created to potentially increase (or decrease) bird species richness.

What Watershed Agreement outcomes may benefit from actions to improve bird species?

Implementation of restoration and conservation related BMPs with the primary goal to improve bird species diversity may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to improve bird diversity
- Healthy watersheds – current healthy watersheds and waters remain healthy, including biodiversity
- Public access site development – public access opportunities for boating, swimming, fishing, including presence of charismatic fauna attractive to public activity
- Protected lands – protect lands identified as high conservation priorities, including lands for bird habitat

What Watershed Agreement outcomes may directly help improve bird species?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to bird species diversity:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including habitat for birds
- Black duck – enhance and preserve habitats supporting wintering black ducks, which could provide habitat for other co-occuring bird species
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including as habitat for birds
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including as habitat for birds
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits for bird species diversity

What best management practices (BMPs) may help improve bird species richness?

Some best management practices may help improve bird species richness (Fig. 3.3.2). BMPs that increase habitat used by birds are especially important. We quantified how BMPs that increase potential bird habitat contribute to changes in bird species richness using a species-area curve describing how species richness (S) changes with acres of habitat (A). Table 3.3.1 below shows estimates for bird species richness for different BMPs based on 20 acres of BMP implementation.

Table 3.3.1. Species area curves to describe species richness for acres of BMP implementation, and potential richness with 20 acres.

BMP NAME	POTENTIAL BIRD SPECIES RICHNESS	EQUATION TO ESTIMATE SPECIES RICHNESS
AG FOREST BUFFERS	77	S=68.97505379*A^0.0382277
AG TREE PLANTING	77	S=68.97505379*A^0.0382277
COVER CROPS	76	S=67.089448*A^0.04234895

FOREST CONSERVATION	77	S=68.97505379*A^0.0382277
GRASS BUFFERS	76	S=67.089448*A^0.04234895
IMPERVIOUS SURFACE REDUCTION	76	S=67.089448*A^0.04234895
URBAN FOREST BUFFER	83	S=71.361518*A^0.0535650
URBAN FOREST PLANTING	83	S=71.361518*A^0.0535650
URBAN TREE PLANTING	85	S=73.325800*A^0.0502914
WETLAND CREATION	92	S=84.59380187*A^0.0293969
WETLAND RESTORATION	92	S=84.59380187*A^0.0293969

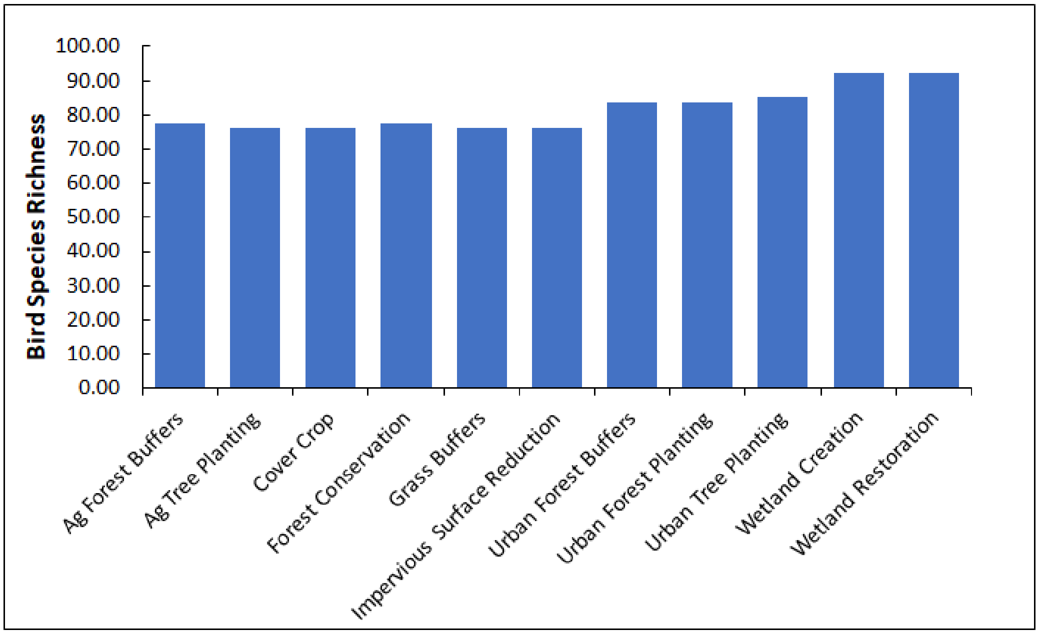


Figure 3.3.2 Potential bird species richness for 20 acres of different BMPs.

Additional Resources

USGS Gap: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap

3.4. Carbon Sequestration

Why is carbon sequestration important?

Carbon sequestration is important to consider in combatting climate change and sea level rise, and in ecosystem resiliency.

Who is impacted by carbon sequestration?

Carbon sequestration benefits many user groups including residents and the global community. Farmers, municipalities, and other organizations may benefit from carbon sequestration if they implement practices that can be used in carbon markets, or as blue carbon credits for coastal ecosystems.

How do we quantify carbon sequestration?

To quantify carbon sequestration, we chose the metric of soil carbon sequestration. Rates of burial of carbon into soil are often associated with long-term removal of carbon from the atmosphere (in support of mitigating climate change) than other sources of temporary carbon removal with faster turnover (such as into vegetative biomass). The amount, or stock, of sequestered carbon stored in soil can be a measure of soil nutrient quality (see **Section 3.10**). Briefly, we used literature and existing tools (e.g., COMET-Planner) to identify rates of soil carbon sequestration from different land uses and common best management practices. We took an average of these reported rates and multiplied them by the respective land use or BMP to estimate total soil carbon sequestration for a certain area (**Appendix A4**). Counties throughout the watershed had different levels of carbon sequestration depending on land cover (Fig. 3.4.1).

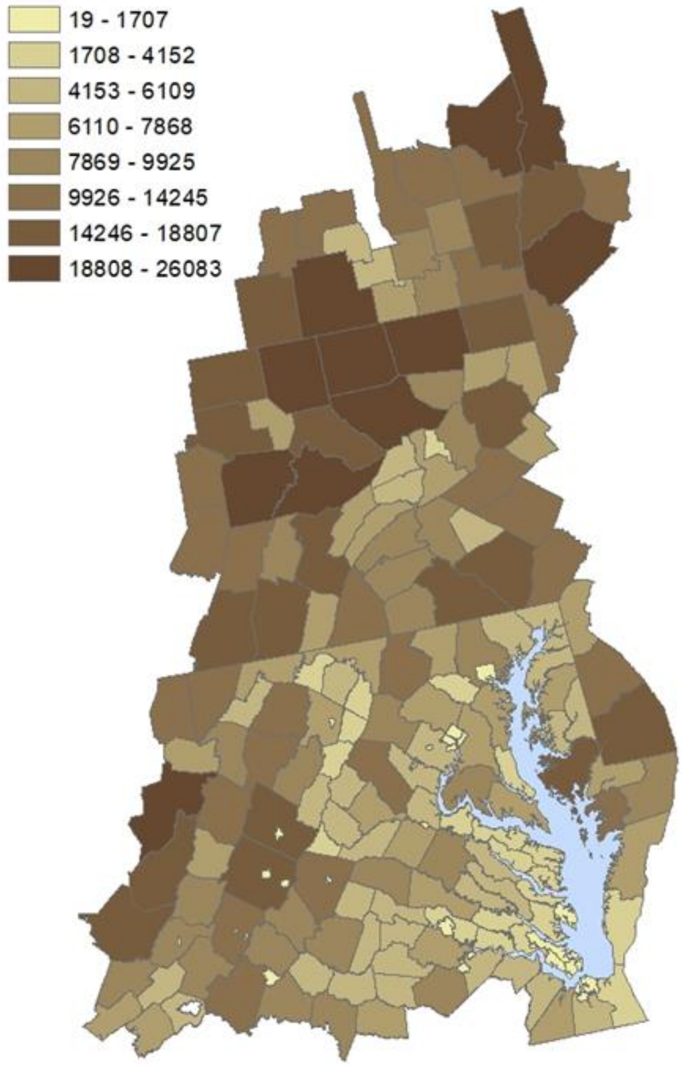


Figure 3.4.1. Estimated soil carbon sequestration (US tons per year) by county based on landuse.

Limitations

Soil carbon sequestration rates were found in the literature and existing tools (e.g., COMET-Planner) and we used the average of the reported rates per land use and/or best management practice.

How can this information be used?

Users can explore the current estimate of soil carbon sequestration for their county and then explore the relationships between different BMPs and soil carbon sequestration to determine if there are practices that may optimize soil carbon sequestration.

What Watershed Agreement outcomes may benefit from actions to improve carbon sequestration?

Implementation of restoration and conservation related BMPs with a primary goal of sequestering carbon may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to sequester carbon (blue carbon, carbon markets)
- Adaptation – enhance resiliency of Bay and aquatic ecosystems to climate change, including by sequestering carbon from the atmosphere
- Healthy watersheds – current healthy watersheds and waters remain healthy, including their abilities to sequester and cycle carbon

What Watershed Agreement outcomes may help improve carbon sequestration?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to carbon sequestration:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including sequestering carbon
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including sequestering carbon
- Submerged aquatic vegetation (SAV) - sustain and increase the habitat benefits of SAV, including sequestering carbon
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including sequestering carbon
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to carbon sequestration

What best management practices may help improve carbon sequestration?

Some best management practices may be better at sequestering carbon in soil than others (Fig. 3.4.2). Table 3.4.1 below shows estimates for soil carbon sequestration for different BMPs based on 20 acres of BMP implementation. Units are US tons of carbon/acre/yr.

Table 3.4.1. Estimates for soil carbon sequestration for different BMPs based on 20 acres of BMP implementation. Units are US tons/acre/yr.

BMP	SOIL CARBON MULTIPLIER (US TONS/ACRE/YR)	SOIL CARBON SEQUESTERED IN 20 ACRES	SOURCE OF MULTIPLIER
AG FOREST BUFFERS	0.18	3.60	COMET
AG TREE PLANTING	0.16	3.27	COMET

COVER CROPS	0.13	2.63	COMET
FOREST CONSERVATION	0.54	10.72	literature
GRASS BUFFERS	0.15	3.01	COMET
IMPERVIOUS SURFACE REDUCTION	0.62	12.41	literature
URBAN FOREST BUFFERS	0.06	1.26	literature
URBAN FOREST PLANTING	0.06	1.26	literature
URBAN TREE PLANTING	0.06	1.26	literature
WETLAND CREATION	0.76	15.12	literature
WETLAND RESTORATION	0.76	15.12	literature

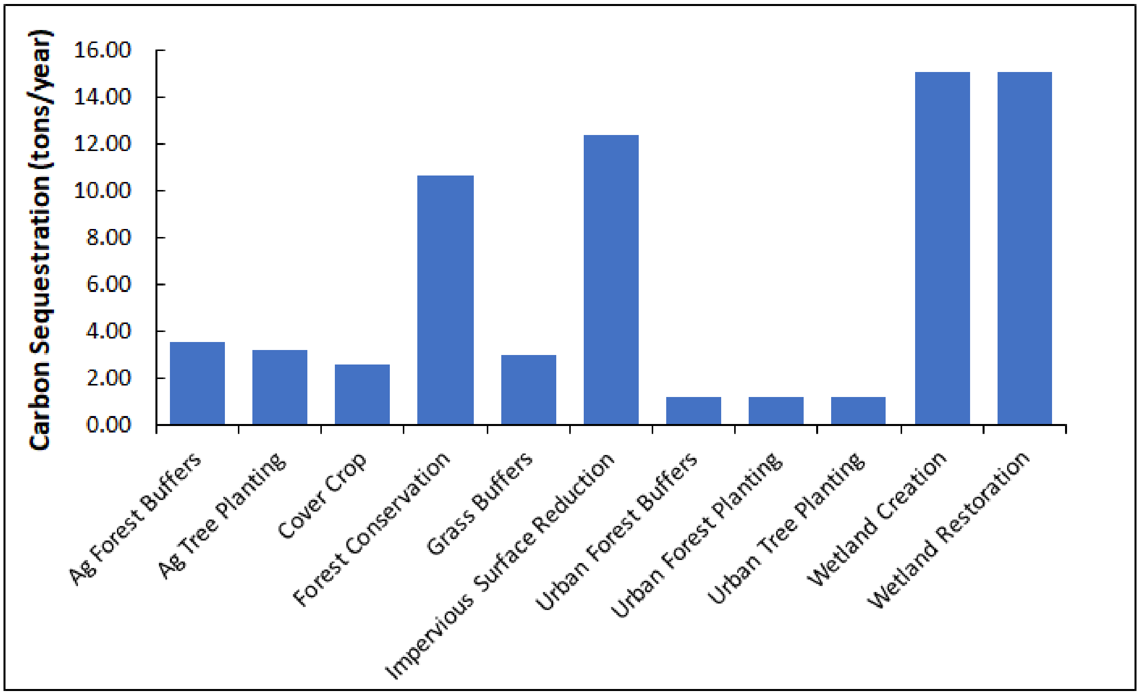


Figure 3.4.2. Soil C sequestration for 20 acres of different BMPs. Missing values are due to insufficient data to calculate the metric for that BMP.

Additional Resources

COMET: http://comet-farm.com/

3.5. Flood Control

Why is flood control important?

Flood control is important because floods can be devastating to ecosystems, humans and property. Understanding what actions may aid flood control is particularly important in areas that are more susceptible to flooding events.

Who is impacted by flood control?

There are many beneficiaries, or users of an ecosystem, that benefit from flood control. For example, business owners, homeowners and renters all benefit when flood control is improved, and their homes and businesses do not flood. Similarly, farmers benefit from flood control for crop and livestock protection.

How do we quantify flood control?

One way to quantify flood control is to quantify the capacity of the landscape to retain excess water. We quantified the maximum retention volume (in^3/in^2) for each landcover class in the watershed using the curve number (CN) method. The ability of a landscape to absorb rainwater depends on vegetation intercepting precipitation and the ability of soil to retain moisture. We associated landcover and soil types with each BMP in order to estimate maximum retention (Appendix A5). Counties throughout the watershed had different levels of water retention depending on land cover (Fig. 3.5.1).

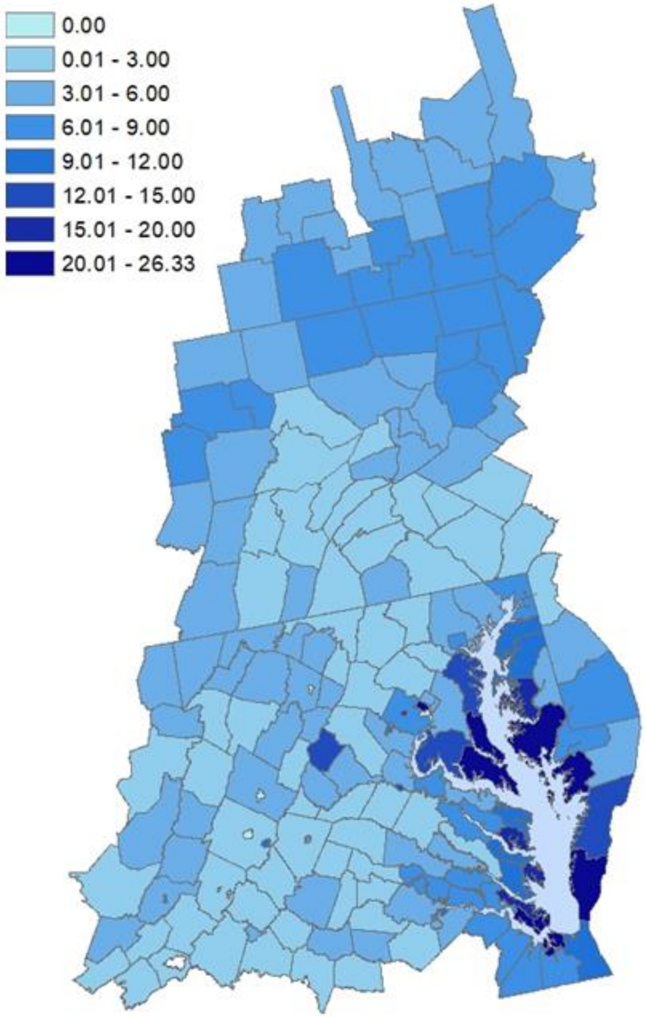


Figure 3.5.1. Estimated maximum water retention for each county in the watershed based on soil type and land use land cover using curve number methods.

Limitations

This method relies on remotely sensed data from 2013/2014 and as such may not entirely reflect current (2021/2022) land use conditions. Additionally, the curve number method is a simple way to estimate water retention on the landscape and should be used as an estimate.

How can this information be used?

Users can explore the current estimate of flood risk for their county and estimated maximum water retention. Then they can explore the relationships between different land uses and water retention to determine if there are certain land uses that can be restored or created to potentially increase (or decrease) flood control.

What Watershed Agreement outcomes may benefit from actions to promote flood control?

Implementation of restoration and conservation related BMPs with a primary goal of flood control may contribute toward achieving the following outcomes

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented for flood control
- Adaptation – enhance resiliency of Bay and aquatic ecosystems to climate change, including by mitigating impacts of flood events
- Black duck – enhance and preserve habitats supporting wintering black ducks, including reducing impacts of flooding that can destroy nests
- Blue crab abundance – maintain a sustainable blue crab population, including reducing impacts of flooding that can alter salinity levels, impact crab distributions, and flood burrows
- Fish habitat – improve fish habitat, critical spawning, nursery and forage areas, including reducing impacts of flooding that can inundate critical habitats, alter salinity levels, or redistribute sediments and pollutants
- Healthy watersheds - current healthy watersheds and waters remain healthy, including reducing impacts of extreme flood events
- Public access site development – public access opportunities for boating, swimming, fishing, including by reducing flood impacts to public access and safety
- Stream health – continually improve stream health and function, including reducing extreme flood events
- Toxic contaminants policy and prevention - reduce and prevent effects of toxic contaminants that harm aquatic systems and humans, including flood events that can redistribute contaminants or increase likelihood of human contact with contaminated waters

What Watershed Agreement outcomes may directly impact flood control?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to flood control:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including mitigating flooding events
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including mitigating flooding events
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including mitigating flooding events
- Protected lands – protect lands identified as high conservation priorities, including wetlands and forests that help to mitigate flooding events
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to flood control

What best management practices (BMPs) may help improve flood control?

Some best management practices may help improve flood control by increasing water retention (Fig. 3.5.2). BMPs that may slow and/or trap runoff may be especially important. We quantified how BMPs contribute to changes in flood control. Table 3.5.1 below shows estimates flood control potential for different BMPs.

Table 3.5.1. Estimates of rainwater retention volume as a proxy for flood control for each BMP. Cubic inches of water retained per square inch were converted to cubic yards per acre of BMP implementation.

BMP NAME	MAX RETENTION VOLUME (IN^3/IN^2)	MAX RETENTION VOLUME (YD^3/ACRE)
AG FOREST BUFFERS	8.16	1097.13
AG TREE PLANTING	8.16	1097.13
COVER CROPS	3.27	439.66
FOREST CONSERVATION	8.16	1097.13
GRASS BUFFERS	3.27	439.66
IMPERVIOUS SURFACE REDUCTION	3.27	439.66
URBAN FOREST BUFFERS	8.16	1097.13
URBAN FOREST PLANTING	8.16	1097.13
URBAN TREE PLANTING	1.47	197.64
WETLAND CREATION	1.1	147.90
WETLAND RESTORATION	1.1	147.90

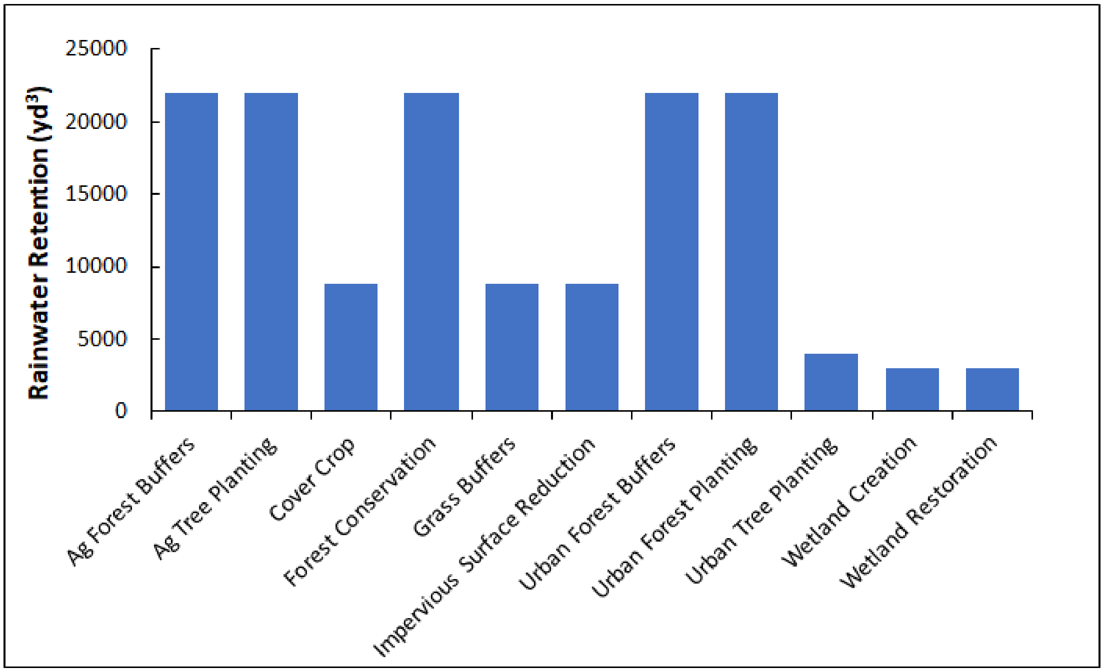


Figure 3.5.2. Maximum rainwater retention for 20 acres of different BMPs

The curve number methodology is a fairly simple approach to measure the maximum rainwater storage capacity of the landscape during a major precipitation event, and has been used as a component toward estimating flood risk (e.g., First Street Foundation, Fig. 3.5.3).

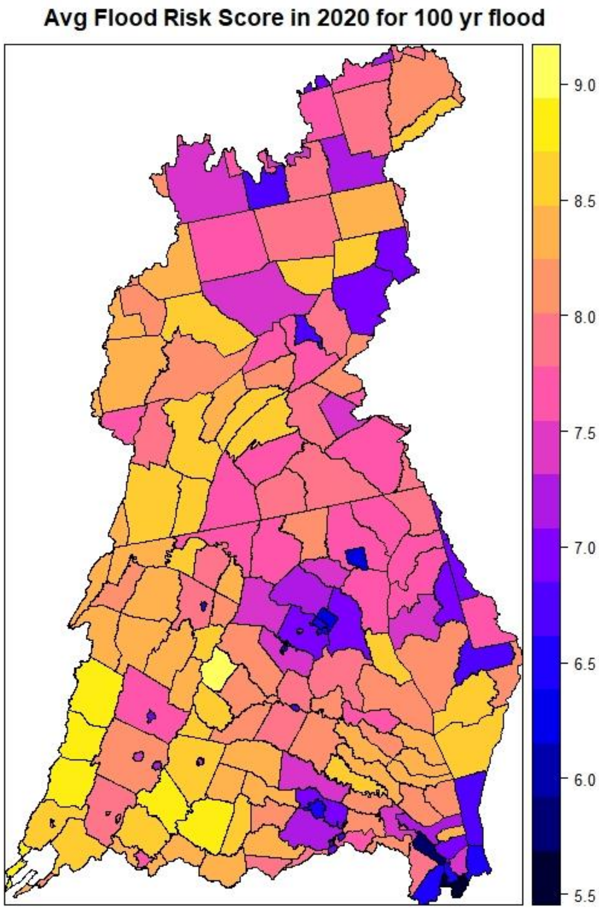


Figure 3.5.3. Average flood risk score in each county in the watershed for a 100-year flood event, where 1 is minimal risk and 10 is extreme risk. Data adapted from First Street Flood Foundation publicly available data. Flood risk data is provided by Flood Factor®, a product of First Street Foundation®. The Flood Factor model is designed to approximate flood risk and not intended to include all possible risks of flood.

Additional Resources

Flood Risk Scores from First Street Foundation®: https://firststreet.org/data-access/public-access/

USDA and NRCS 1986. Urban hydrology for small watersheds.

3.6. Heat Risk Reduction

Why is reducing extreme heat important?

Understanding trends in temperature and potential tools to reduce temperature is important because of climate change and associated health risks with extreme heat.

Who is impacted by reducing temperature extremes?

There are many beneficiaries, or users of an ecosystem, that may benefit from reduced air temperature. For example, energy providers may have less demand during peak summer temperatures if indoor temperatures can be reduced through natural solutions, such as shading. Likewise, residents may benefit if they experience cooler outdoor spaces for recreation during peak summer temperatures.

How do we quantify reduced air temperature?

We quantified cooling impact of tree canopy to estimate temperature reduction. Briefly, we obtained daily average July temperatures for every county and land river segment in the watershed from CAST. Then, we plotted acres of tree canopy against the average daily air temperature to determine if a relationship existed (see **Appendix A6** for details). We found that tree canopy alone explained ~44% of the differences in temperatures. Counties throughout the watershed had different levels of air temperature reduction related to the amount of tree canopy cover (Fig. 3.6.1).

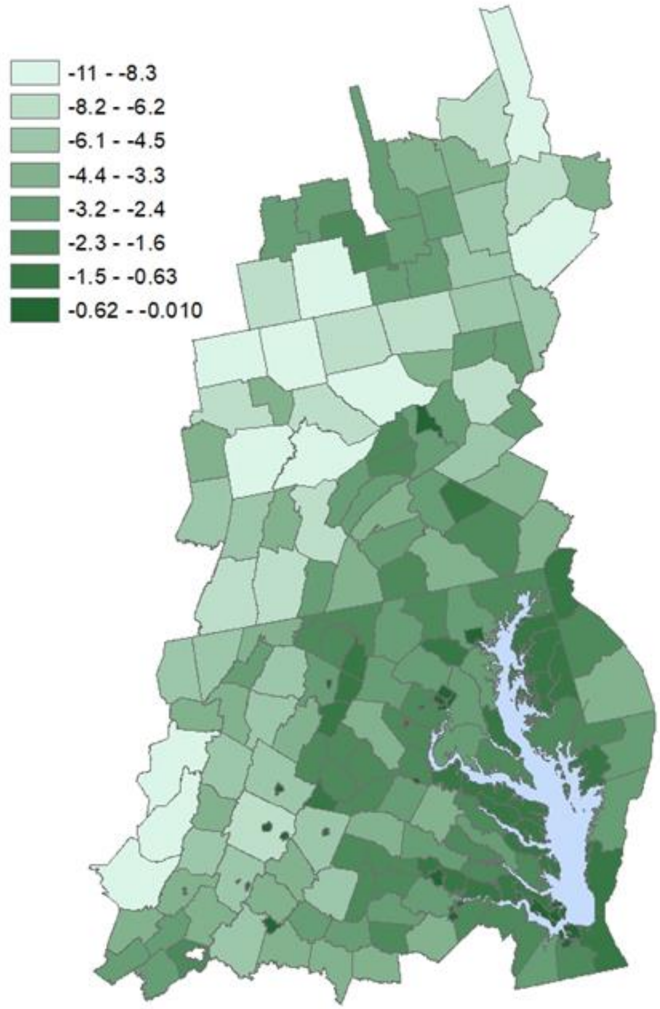


Figure 3.6.1. Estimated cooling impact from trees by county, measured as reduction in mean July daily air temperatures (°F) due to presence of tree canopy.

Limitations

This method relies on remotely sensed data from 2013/2014 and as such may not entirely reflect current (2021/2022) land use conditions. Only BMPs that have the potential to impact tree canopy were considered, as tree canopy was the only land cover with a significant cooling effect in predictive models (see **Appendix A6** for details). Model estimates are based on county scale or sub-watershed scale average temperatures, which may be appreciably smaller than local scale cooling effects (i.e., the reduction in air temperature under a single tree).

How can this information be used?

Users can explore the current estimate of cooling due to tree canopy for their county and consider whether it would be beneficial to add more tree canopy.

What Watershed Agreement outcomes may benefit from actions to reduce extreme temperatures?

Implementation of restoration and conservation related BMPs with a primary goal of regulating extreme temperatures may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to regulate temperatures through shading
- Adaptation – enhance resiliency of Bay and aquatic ecosystems to climate change, including reducing extreme temperature fluctuations
- Healthy watersheds – current healthy watersheds and waters remain healthy, including reducing extreme temperatures
- Brook trout – restore and sustain naturally reproducing brook trout in headwater streams, including reducing temperature extremes through shading
- Fish habitat – improve fish habitat, critical spawning, nursery, and forage areas, including reducing temperature extremes through shading
- Stream health – continually improve stream health and function, including reducing temperature extremes through shading
- Public access site development – public access opportunities for boating, swimming, fishing, including regulating temperatures favorable and safe for human activity

What Watershed Agreement outcomes may help improve or reduce extreme temperatures?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to temperatures:

- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including to create shading and regulate extreme temperatures
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including to create shading and regulate extreme temperatures
- Protected lands – protect lands identified as high conservation priorities, including forests that help to create shading and regulate extreme temperatures
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to regulating extreme temperatures

What best management practices (BMPs) may help mitigate extreme air temperatures?

Some best management practices may help reduce air temperature and therefore reduce heat risk. BMPs that provide shade are likely to help to reduce air temperatures. We quantified how BMPs may contribute to changes in mean summer air temperatures at the county scale. Table 3.6.1 and Fig. 3.6.2 below shows estimates of mean temperature differences at the county scale for different BMPs based on 20 acres of BMP implementation. Units are in °F. Because models are based on contiguous tree canopy cover, BMPs which do not appreciably change tree canopy (e.g., cover crops, herbaceous wetlands, impervious surface reduction) are assumed to not appreciably reduce temperatures.

Table 3.6.1. Estimates of temperature reduction due to 20 acres of tree canopy.

BMP NAME	TEMPERATURE REDUCTION (°F) PER ACRE OF TREE CANOPY	TEMPERATURE REDUCTION (°F) BY 20 ACRES OF TREE CANOPY
AG FOREST BUFFERS AG TREE PLANTING FOREST CONSERVATION URBAN FOREST BUFFERS URBAN FOREST PLANTING URBAN TREE PLANTING	-0.00001584 x acres of tree canopy	-0.00032

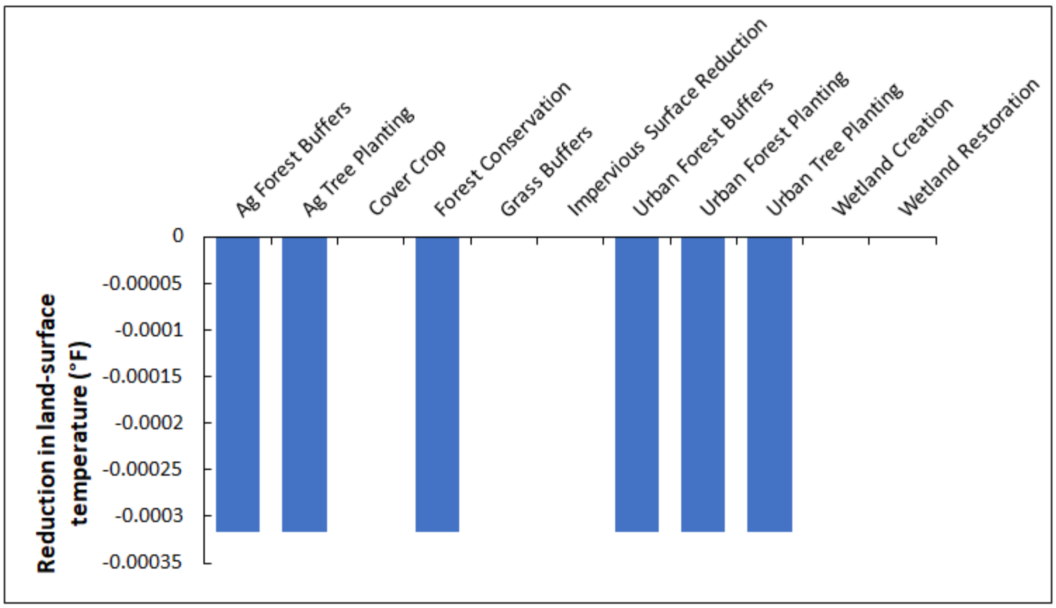


Figure 3.6.2. Cooling potential based on the reduction in temperature (°F) for 20 acres of tree canopy.

Additional Resources

City of Cambridge Massachusetts. 2015. Climate Change Vulnerability Assessment. Part 1. City of Cambridge, Massachusetts.

Murphy, D.J., M.H. Hall, C.A.S. Hall, G.M. Heisler, S.V. Stehman, and C. Anselmi-Molina. 2011. The relationship between land cover and the urban heat island in northeastern Puerto Rico. International Journal of Climatology 31:1222-1239.

3.7. Open Space

Why is open space important?

Open space, or green space, provides many benefits to many different user groups. It provides opportunities for recreation and aesthetic enjoyment which can lead to positive health outcomes such as increased physical activity.

Who is impacted by presence of open space?

There are many user groups that benefit from open space. For example, residents may benefit from open space as a place to walk or enjoy the outdoors. Hunters and anglers benefit from open space where they can safely hunt or fish. Open space may also be a part of scenic landscapes, even if direct public access is limited.

How do we quantify open space?

For open space, we have chosen to quantify open space available per capita. First, we quantified total acres of open space per county which included the following land uses: wetlands, tree canopy, shrubland, and low vegetation. We assume open space is contiguous of an appreciable size (e.g., more than a single tree), and accessible to people. We used census data (2010) to determine the population per county. Next, we divided total acres of open space by the county population. Counties throughout the watershed had different levels of open space per person (Fig. 3.7.1).

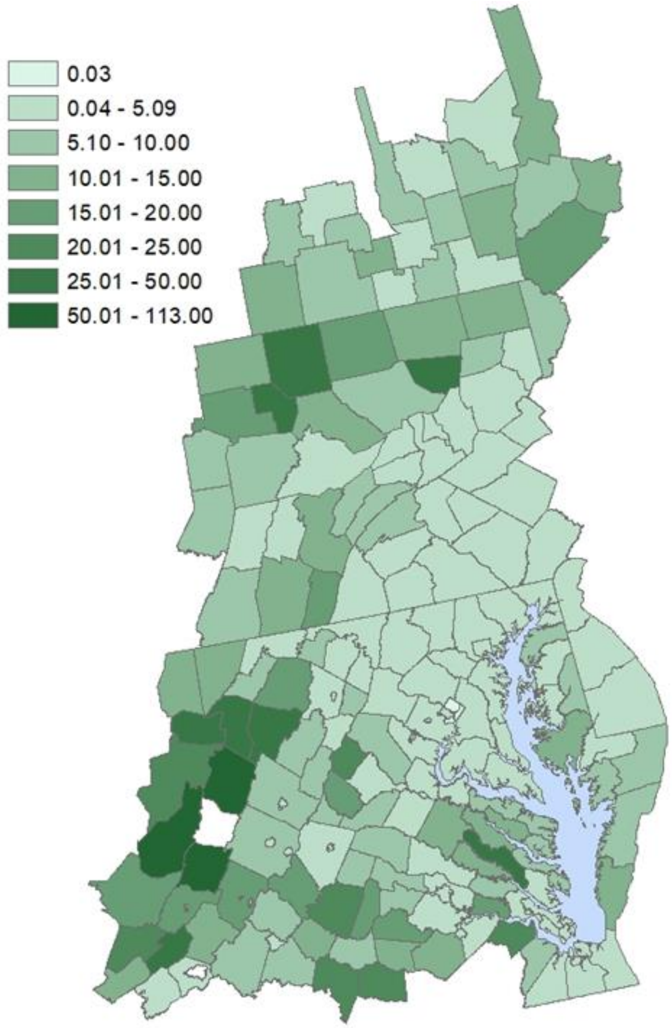


Figure 3.7.1. Total acres of open space per capita. Here open space is defined as wetland, tree canopy, shrubland, and low vegetation in a contiguous area and accessible to people for recreational or aesthetic enjoyment.

Limitations

This is based on remotely sensed land cover from 2013/2014 and may be an overestimate of usable open space as this dataset does not include access (e.g., discerning private vs public lands).

How can this information be used?

Users can explore the current estimate of open space per capita for their county and then consider what best management practices could be implemented to help increase open space available.

What Watershed Agreement outcomes may benefit from actions to improve open space?

Implementation of restoration and conservation related BMPs with a primary goal of creating open space may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to create open space or green space
- Black duck – enhance and preserve habitats supporting wintering black ducks, including by creating or restoring green space such as wetlands
- Blue crab abundance – maintain a sustainable blue crab population, including by creating or restoring green space such as wetlands
- Fish habitat – improve fish habitat, critical spawning, nursery and forage areas, including by creating or restoring green space such as wetlands
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including by creating forested green space
- Healthy watersheds – current healthy watersheds and waters remain healthy, including by preserving and creating green space
- Oysters - restore native oyster habitat and populations, including by creating or restoring green space such as wetlands
- Protected lands – protect additional acres of land throughout the watershed, including forested or wetland green space
- Public access site development – public access opportunities for boating, swimming, fishing, including access to open space or green space
- Submerged aquatic vegetation (SAV) - sustain and increase the habitat benefits of SAV, including by creating or restoring green space such as wetlands
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including by creating forested green space
- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including by creating or restoring acres of wetland green space

What best management practices (BMPs) may help improve open space?

Some best management practices may help improve open space (Fig. 3.7.2). BMPs that increase wetland, tree canopy, shrubland and/or low vegetation cover would have positive impacts on open space (see **Appendix A7** for details). Urban tree plantings and impervious surface reduction are assumed to contribute to open areas if they are planted in a contiguous area of appreciable size (i.e., more than a single tree). Agricultural tree plantings, such as to reduce erosion, and cover crops are assumed here not to be open space that is accessible to the public for recreational or aesthetic enjoyment. As BMPs add acres of land use considered open space, then open space will increase. Per capita value of open space depends on the specific location of implementation.

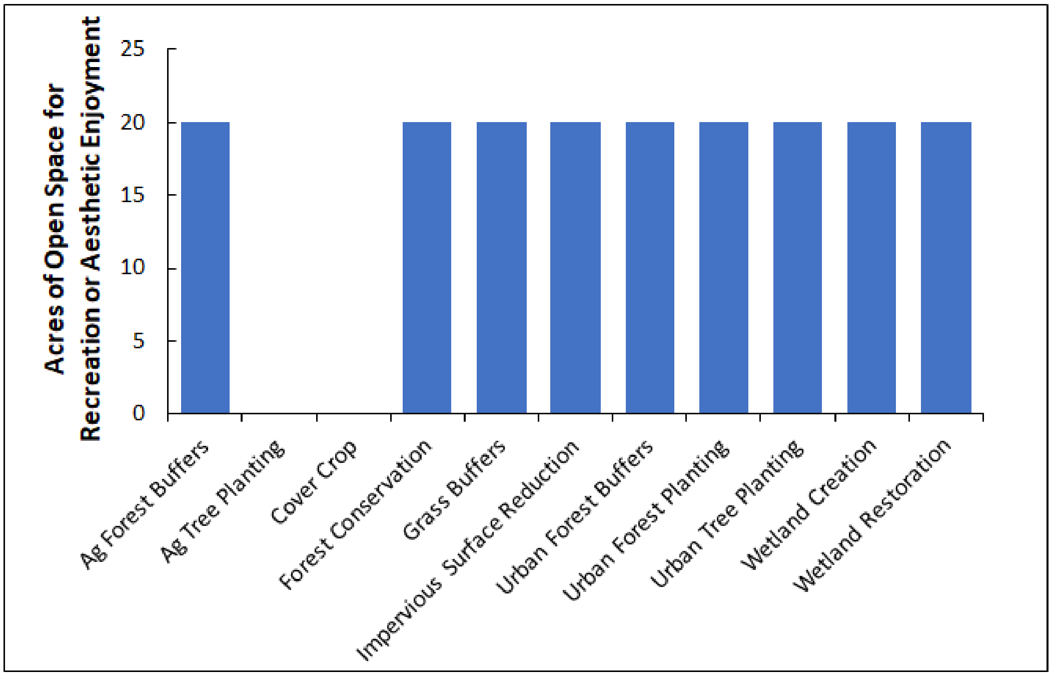


Figure 3.7.2. Open space acres added for 20 acres of each BMP. Open space per capita will depend on the specific location of the added acres. Urban tree planting was considered publicly beneficial open space if it was of contiguous area (i.e., more than a single tree), however agricultural tree planting and cover crops were generally considered to be not publicly accessible for recreation or aesthetic enjoyment.

Additional Resources

United States Environmental Protection Agency. EnviroAtlas. Eco-Health Relationship Browser. Retrieved: January 24, 2022 from https://www.epa.gov/enviroatlas/enviroatlas-eco-health-relationship-browser.

3.8. Pathogen Reduction

Why is pathogen reduction important?

Reducing pathogen loads in water sources is important for ecosystem health, livestock health and human health.

Who is impacted by reducing pathogens in water?

There are many beneficiaries, or users of an ecosystem, that benefit from reducing pathogens in waterbodies. For example, reduced pathogens in water keeps waterbodies open for recreation which benefits resident and tourists.

How do we quantify pathogen reduction?

To quantify pathogen reduction in water, we chose the metric percent fecal indicator bacteria (FIB) removal. This metric includes fecal coliform and *E. coli* removal rates which are often used as indicators for other pathogens (Wainger et al., 2015; Richkus et al., 2016). Counties throughout the watershed have different levels of pathogen loading, depending on land cover (Fig. 3.8.1). The potential reduction in FIB by each BMP land cover depends on the land use on which they are applied. At a county-scale, the % FIB removal resulting from BMP implementation can be calculated as the relative contribution of FIB removal of the new BMP acres relative to the total acres of landuse on which they were applied (Wainger et al., 2015; Richkus et al., 2016). Forest buffer, for example, has a removal efficiency of 50% for FIB entering the buffer from pasture land. At a county scale, if 100 acres of forest buffer are implemented on 1000 acres of pasture, an overall reduction of 100/1000 x 50% = 5% could be estimated due to the presence of the forest buffer.

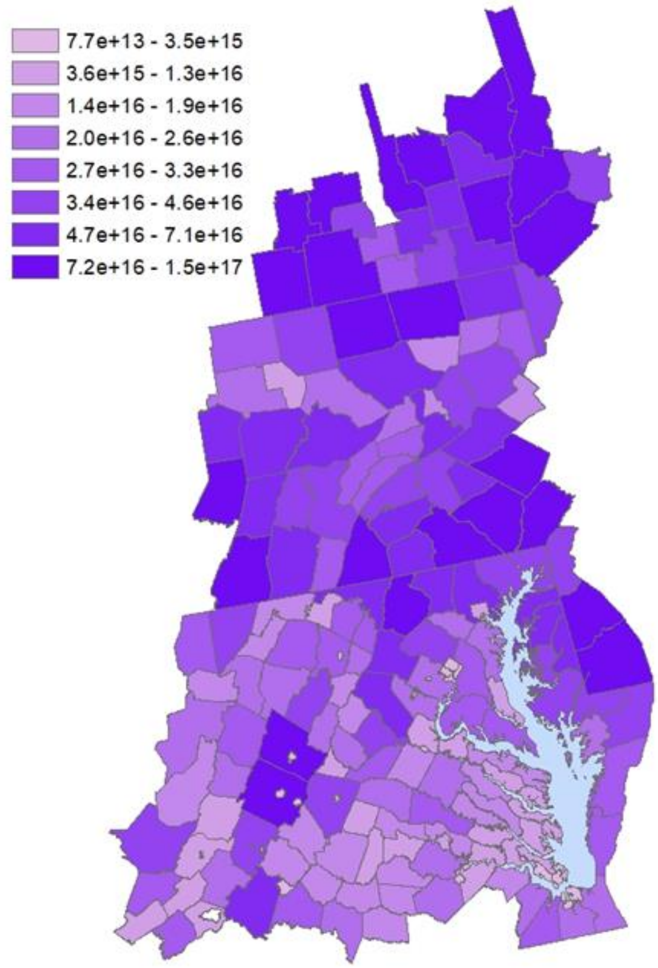


Figure 3.8.1. Estimated total pathogen load (fecal coliform, CFU per year) per county based on pasture and urban loads. A portion of fecal bacteria are filtered by ecosystems before reaching streams or other waterbodies.

Limitations

% FIB removal efficiencies are based on literature values from a variety of locations and may not be specific to the Chesapeake Bay Watershed and are not inclusive of all BMPs implemented, therefore this is likely an underestimate of total % FIB removal. This method also relies on remotely sensed data from 2013/2014 and as such may not entirely reflect current (2021/2022) land use conditions in the watershed.

How can this information be used?

Users can explore the total potential % FIB removal due to the proposed acres for Forest Buffers, Grass Buffers, Impervious Surface Reduction and Wetland Restoration in their county. Users can compare % FIB removal efficiencies between these BMPs and determine if they would like to optimize pathogen reduction.

What Watershed Agreement outcomes may benefit from actions to reduce pathogen loading?

Implementation of restoration and conservation related BMPs with a primary goal of reducing pathogen loads may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented for reducing pathogen loads
- Black duck – enhance and preserve habitats supporting wintering black ducks, including reducing pathogens
- Brook trout – restore and sustain naturally reproducing brook trout in headwater streams, including reducing pathogens
- Healthy watersheds - current healthy watersheds and waters remain healthy, including reducing pathogens
- Oysters - restore native oyster habitat and populations, including reducing pathogens
- Public access site development – public access opportunities for boating, swimming, fishing, including by reducing pathogens that could impact public safety
- Stream health – continually improve stream health and function, including reducing pathogens
- Submerged aquatic vegetation (SAV) - sustain and increase the habitat benefits of SAV, including reducing pathogens
- Toxic contaminants policy and prevention - reduce and prevent effects of toxic contaminants that harm aquatic systems and humans, including reducing pathogens

What Watershed Agreement outcomes may help reduce pathogen loading?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to reducing pathogens:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including buffering pathogens
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including buffering pathogens
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including buffering pathogens
- Protected lands – protect lands identified as high conservation priorities, including forests and wetlands that reduce pathogen loads
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to reducing pathogen loads

What best management practices (BMPs) may help reduce pathogen loading?

There are many BMPs that may help with pathogen reduction (Fig. 3.8.2). Here we focused specifically on Forest buffers, Grass buffers, Impervious Surface Reduction and Wetland restoration. The table below shows estimates for average % FIB reduction of county-wide loadings for different BMPs based on

20 acres of BMP implementation in each county. Total land acres where the BMPs were applied were assumed to be either low vegetation in agricultural/rural areas or impervious surfaces in urban areas (see **Appendix A8** for details). Units are % FIB removal.

Table 3.8.1. Estimates of mean %FIB removal due to 20 acres of BMP implementation on either low vegetation or urban lands in each county.

BMP NAME	% FIB REMOVAL	% FIB REMOVAL EQUATION
AG FOREST BUFFERS	0.0434	(Acres of BMP / total land acres where BMP applied) * 50%
AG FOREST BUFFERS FENCED	0.045136	(Acres of BMP / total land acres where BMP applied) * 52%
GRASS BUFFERS	0.0616	(Acres of BMP / total land acres where BMP applied) * 71%
GRASS BUFFERS FENCED	0.0616	(Acres of BMP / total land acres where BMP applied) * 71%
IMPERVIOUS SURFACE REDUCTION	0.0001	(Acres of BMP / total land acres where BMP applied) * 57%
URBAN FOREST BUFFERS	0.000088	(Acres of BMP / total land acres where BMP applied) * 50%
URBAN FOREST PLANTING	0.000088	(Acres of BMP / total land acres where BMP applied) * 50%
WETLAND CREATION/RESTORATION	0.0304	(Acres of BMP / total land acres where BMP applied) * 35%

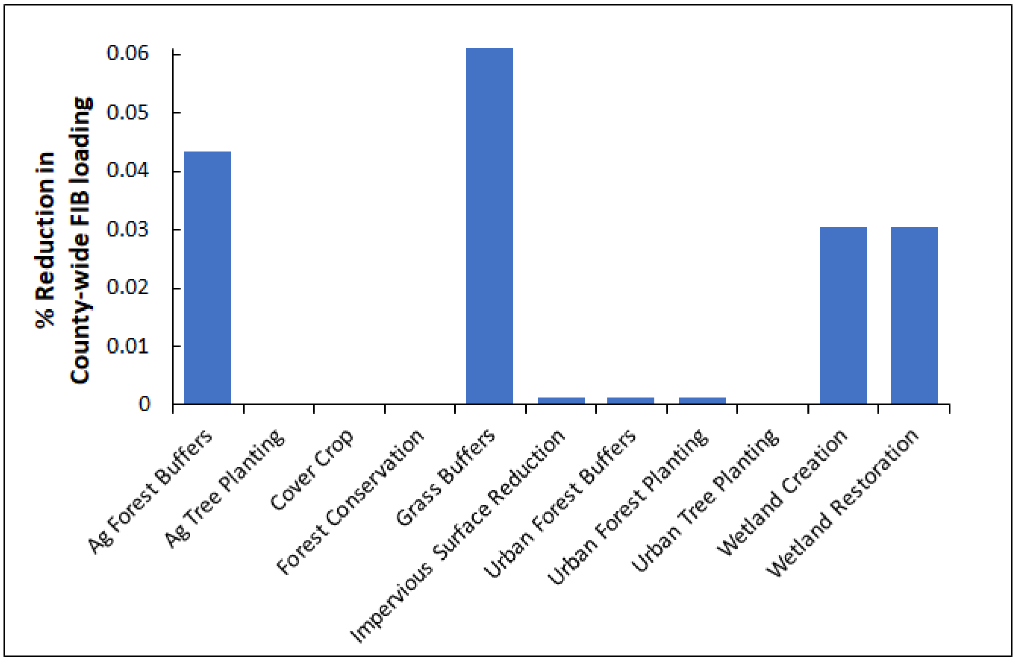


Figure 3.8.2. Percent reduction in county-wide FIB loading with 20 acres of BMP implementation. Missing bars are BMPs for which FIB reductions were not calculated.

Additional Resources

Wainger, L., J. Richkus, M. Barber. 2015. Additional Beneficial Outcomes Of Implementing The Chesapeake Bay TMDL: Quantification And Description Of Ecosystem Services Not Monetized. U.S. Environmental Protection Agency, Washington, DC.

3.9. Pollinators

Why is pollinator supply important to people?

Pollinator supply is important to maintain for any plants requiring pollination. This is especially important for agriculture.

Who is impacted by pollinator supply?

There are many beneficiaries, or users of an ecosystem, that benefit from pollinators. For example, farmers may benefit from natural pollinators depending on the crop they harvest. Residents may benefit from pollinators (e.g., butterflies) through wildlife viewing.

How do we quantify pollinator supply?

To quantify pollinator supply we chose to use a model developed by InVEST (Sharpe et al., 2020). This model considers floral resource availability and pollinator activity during a particular season. For our purposes we looked at summer season pollinator habitat suitability for a handful of species (though we only show bumblebee in the map in Fig. 3.9.1). Higher suitability scores indicate sources of greater relative bee abundance. Counties throughout the watershed had different suitability as bumblebee habitat (Fig. 3.9.1).

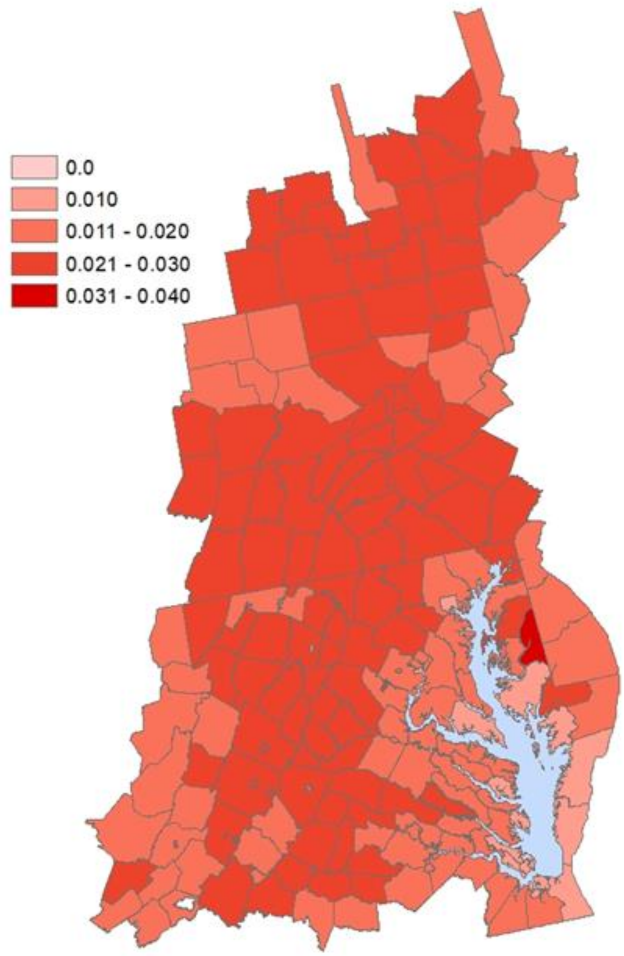


Figure 3.9.1. Bumblebee abundance Index ranges from 0-1 and reflects where bumblebees are active as a result of floral resources during the given season (here, summer).

Limitations

We used the InVEST model to determine an index of pollinator supply and abundance (see Appendix A9 for details). This method relies on land cover land use data from 2013/14 and is not the most up to date land use for the watershed.

How can this information be used?

Users can explore the current estimate of a pollinator species abundance for their county and then explore the relationships between different land uses and pollinator abundance to determine if there are certain land uses that can be restored or created to potentially increase (or decrease) a certain pollinator abundance.

What Watershed Agreement outcomes may benefit from actions to improve pollinator supply?

Implementation of restoration and conservation related BMPs with a primary goal of increasing and improving pollinator habitat may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those creating or restoring pollinator habitat
- Healthy watersheds – current healthy watersheds and waters remain healthy, including protecting critical pollinators
- Protected lands – protect additional acres of land throughout the watershed, including habitats favorable for pollinators
- Public access site development – public access opportunities for boating, swimming, fishing, including access to wildlife viewing of pollinator species

What Watershed Agreement outcomes may help improve pollinator supply?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to improving pollinator supply:

- Black duck – enhance and preserve habitats supporting wintering black ducks, which may also provide shared habitat for pollinators
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including as habitat for pollinators
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including as habitat for pollinators
- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including as habitat for pollinators
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, some of which may contribute to pollinator habitat

What best management practices (BMPs) may help improve pollinator supply?

Some best management practices may help improve pollinator supply and abundance (Fig. 3.9.2). BMPs that increase floral resources are especially important. Table 3.9.1 below shows estimates of mean index of abundance (0-1) in summer for four bee species for different land uses in the watershed.

Table 3.9.1. Estimates of abundance index (0-1) in summer for four bee species for BMP land covers.

BMP NAME	BUMBLEBEE	BICOLOR SWEAT BEE	BLUE SWEAT BEE	ORCHARD BEE
AG FOREST BUFFERS & TREE PLANTING	0.020	0.009	0.009	0.008
CROP COVER	0.044	0.020	0.015	0.013
FOREST CONSERVATION	0.020	0.009	0.009	0.008
GRASS BUFFERS	0.044	0.020	0.015	0.013
IMPERVIOUS SURFACE REDUCTION	0.044	0.020	0.015	0.013
URBAN FOREST BUFFERS/PLANTING	0.020	0.009	0.009	0.008
URBAN TREE PLANTING	0.015	0.007	0.006	0.006
WETLAND CREATION/RESTORATION	0.024	0.008	0.008	0.008

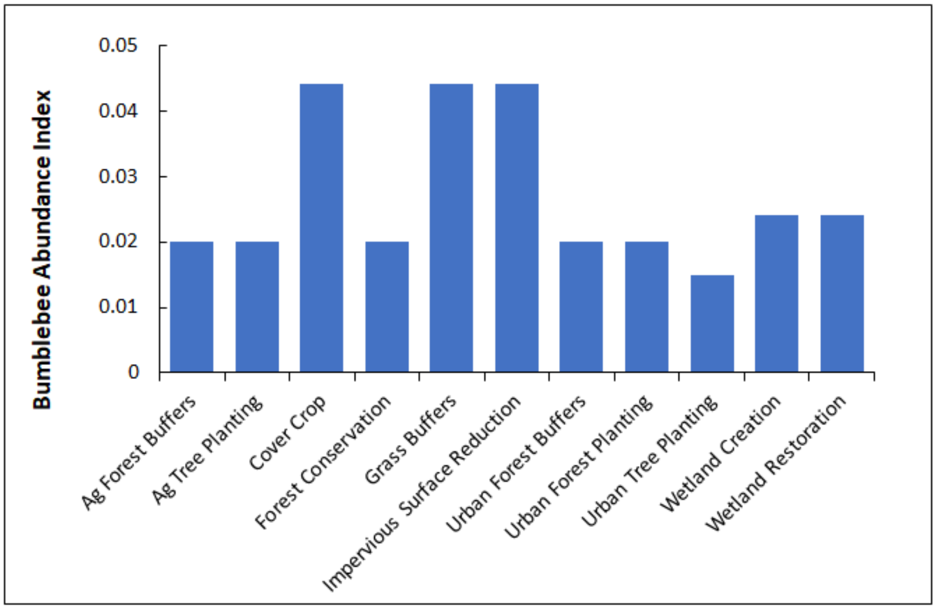


Figure 3.9.2. Bumblebee Abundance Index for different BMPs.

Additional Resources

Sharp, R., J. Douglass, S. Wolny, K. Arkema, J. Bernhardt, W. Bierbower, N. Chaumont, D. Denu, D. Fisher, K. Glowinski, R. Griffin, G. Guannel, A. Guerry, J. Johnson, P. Hamel, C. Kennedy, C. K. Kim, M. Lacayo, E. Lonsdorf, L. Mandle, L. Rogers, J. Silver, J. Toft, G. Verutes, A. L. Vogl, S. Wood, K. Wyatt. 2020. InVEST 3.8.9 User's Guide.

3.10. Soil Quality

Why is soil quality important?

Soil quality is important for crops, and healthy ecosystems.

Who is impacted by soil quality?

Soil quality benefits many user groups. Farmers may benefit from improved soil quality by potentially reducing their need for fertilizer and improving crop production.

How do we quantify soil quality?

To quantify soil quality, we chose to focus on carbon content in soil. Soil carbon is one of many metrics that could be used to determine soil health (e.g., soil moisture, nitrogen content). Soil carbon is a food source for important microorganisms in soil. Briefly, we used literature and existing tools to identify soil carbon stocks from different land uses and common best management practices (see **Appendix A10** for details). Then, we took an average of these reported rates and multiplied them by the respective land use or BMP to estimate total soil carbon stock for a certain area. Counties throughout the watershed had different levels of carbon stock depending on land cover (Fig. 3.10.1).

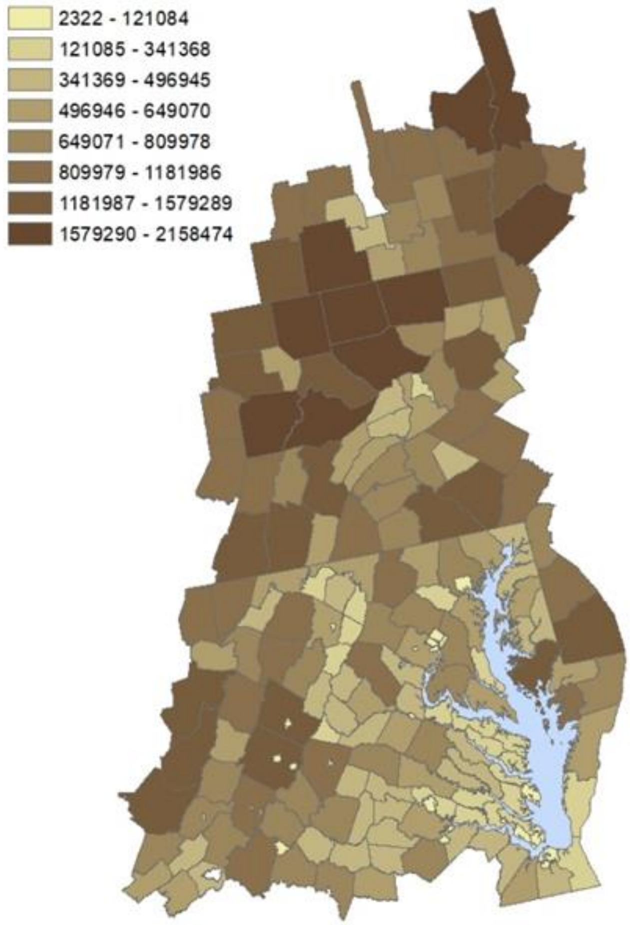


Figure 3.10.1. Estimated soil C stock (US tons) by county based on land use type.

Limitations

Soil carbon stock estimates were found in the literature, and we used the average of the reported stocks per land use and/or best management practice. Soil carbon is only one aspect of soil quality, and may take years to reach the levels of an established ecosystem after implementation. Soil carbon stock, while related to rates of carbon sequestration that remove atmospheric carbon (see **Section 3.4**), measures the current availability of carbon (e.g., as a nutrient) in soil.

How can this information be used?

Users can explore the current estimate of soil carbon stock for their county and then explore the relationships between different BMPs and soil carbon stock to determine if there are practices that may optimize soil carbon stock.

What Watershed Agreement outcomes may benefit from actions to improve soil quality?

Implementation of restoration and conservation related BMPs with a primary goal of increasing and improving pollinator habitat may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to sequester carbon into soil (blue carbon, carbon markets)
- Adaptation – enhance resiliency of Bay and aquatic ecosystems to climate change, including by sequestering carbon from the atmosphere into soil
- Healthy watersheds – current healthy watersheds and waters remain healthy, including their abilities to sequester and cycle carbon

What Watershed Agreement outcomes may help improve soil quality?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to improving soil quality:

- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including storing and retaining carbon, nutrients, and moisture in soil
- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including storing and retaining carbon, nutrients, and moisture in soil
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including storing and retaining carbon, nutrients, and moisture in soil
- Protected lands – protect lands identified as high conservation priorities, including storing and retaining carbon, nutrients, and moisture in soil
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to soil quality

What best management practices (BMPs) may help improve soil quality?

Some best management practices may improve soil quality through increasing soil carbon stocks (Fig. 3.10.2). The table below shows estimates for soil carbon stocks for different BMPs based on 20 acres of BMP implementation. Units are US tons carbon/acre.

Table 3.10.1. Estimates for soil carbon stocks for different BMPs based on 20 acres of BMP implementation. Units are US tons carbon/acre

BMP NAME	SOIL CARBON MULTIPLIER (US TONS/ACRE)	ESTIMATED SOIL CARBON STOCK FOR 20 ACRES
AG FOREST BUFFERS	14.47	289.33
AG TREE PLANTING	14.47	289.33
COVER CROP	1.32	26.31
FOREST CONSERVATION	14.47	289.33
GRASS BUFFERS	12.75	254.93
IMPERVIOUS SURFACE REDUCTION	64.30	1285.92
URBAN FOREST BUFFERS	47.91	958.19
URBAN FOREST PLANTING	47.91	958.19
URBAN TREE PLANTING	47.91	958.19
WETLAND CREATION	65.83	1316.50
WETLAND RESTORATION	65.83	1316.50

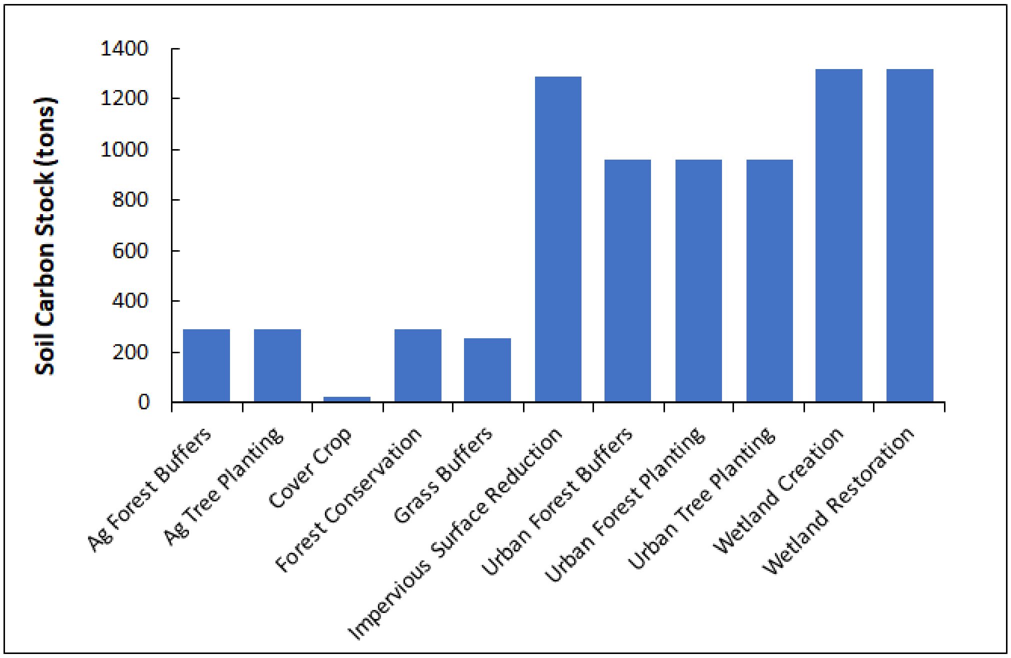


Figure 3.10.2. Soil Carbon stock for 20 acres of different BMPs.

Additional Resources

Pouyat, Richard V., Ian D. Yesilonis, and David J. Nowak. 2006. Carbon storage by urban soils in the United States. Journal of Environmental Quality 35:1566-1575.

3.11. Water Quantity

Why is water quantity important?

Water quantity, or availability, is important for many user groups. Estimating water quantity is important for understanding the movement of water across the landscape.

Who is impacted by water quantity?

There are many beneficiaries, or users of an ecosystem, that benefit from water quantity. For example, it is important to know the water available upstream from a hydropower facility or drinking water facility.

How do we quantify water quantity?

To quantify water quantity, we have chosen to use estimates of annual surface water flow as a proxy to water quantity available on the landscape. This metric considers land cover, elevation, and precipitation (among other factors) to estimate how water flows across a landscape. Water flow is related to flood control (see **Section 3.5**) in that the amount of runoff from the landscape depends in part on the capacity of the land to absorb initial precipitation (curve number method). In general, landscapes (such as impervious surface) with a low capacity to absorb water, will have higher runoff and flow, depending on elevation, slope, distance from stream, and other factors.

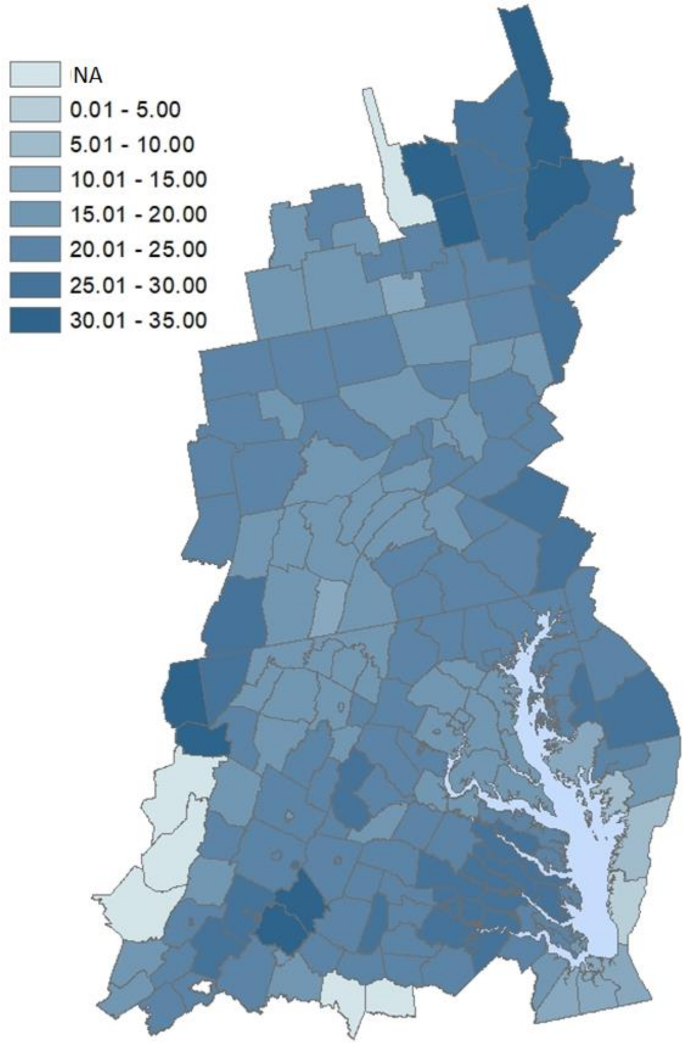


Figure 3.11.1. Mean annual water flow per county based on landcover and many other factors. NA indicates land-river segments predominantly outside the watershed for which stream flow was not estimated.

Limitations

Annual water flow is estimated by a model that uses remotely sensed land cover data (Chesapeake Bay Program, 2020). Land covers such as roads typically have higher average flow as there is less structure in the way to slow water down, and less ability of the land to retain rainwater through infiltration, which can also contribute to more variable (less stable) streamflow. Under extreme precipitation scenarios, high flows can become dangerous and the capacity of the land to retain rainwater can be an indicator of flood risk (see **Section 3.5**).

How can this information be used?

Users can explore the current estimate of annual water flow for their county and then explore the relationships between different land uses and annual water flow to determine if there are certain land uses that can be restored or created to potentially increase or decrease water flow. Counties throughout the watershed had different levels of water flow based on land cover and other factors (Fig. 3.11.1).

What Watershed Agreement outcomes may benefit from actions to improve water quantity?

Implementation of restoration and conservation related BMPs with a primary goal of increasing and improving water flow may contribute toward achieving the following outcomes:

- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, including those implemented to create open space or green space
- Blue crab abundance – maintain a sustainable blue crab population, including by improving and maintaining water flow
- Brook trout – restore and sustain naturally reproducing brook trout in headwater streams, including by improving and maintaining water flow
- Fish habitat – improve fish habitat, critical spawning, nursery and forage areas, including by improving and maintaining water flow
- Healthy watersheds – current healthy watersheds and waters remain healthy, including by improving and maintaining water flow
- Stream health – continually improve stream health and function, including by improving and maintaining water flow

What Watershed Agreement outcomes may help improve water quantity?

Implementation of BMPs to achieve the following watershed agreement outcomes may also lead to additional benefits to improving water flow:

- Forest buffers – restore, converse, and increase capacity of forest buffers to provide benefits, including regulating flow of water
- Tree canopy – expand and increase capacity of tree canopy to provide benefits, including regulating flow of water
- Wetlands – create, reestablish, enhance function and capacity of wetlands to provide benefits, including regulating the flow of water
- Protected lands – protect lands identified as high conservation priorities, including forests and wetlands that help regulate the flow of water
- 2025 WIP – all articulated practices from Chesapeake Bay TMDL document in place by 2025, leading to potential benefits to water flow

What best management practices (BMPs) may impact water quantity?

Some best management practices may help improve annual water flow (Fig. 3.11.2). Table 3.11.1 below shows estimates for annual water flow for different BMPs based on land cover type (see **Appendix A11** for more details). Units are inches per year.

Table 3.11.1. Estimates for annual water flow for different BMPs based on land cover type. Units are inches per year.

BMP NAME	MEAN ANNUAL FLOW (IN/YEAR)
AG FOREST BUFFERS, TREE PLANTING	13.75
COVER CROP	15.62
FOREST CONSERVATION	13.70
GRASS BUFFERS	15.09
IMPERVIOUS SURFACE REDUCTION	19.91
URBAN FOREST BUFFERS AND PLANTING	13.75
URBAN TREE PLANTING	26.17
WETLAND CREATION/RESTORATION	13.70

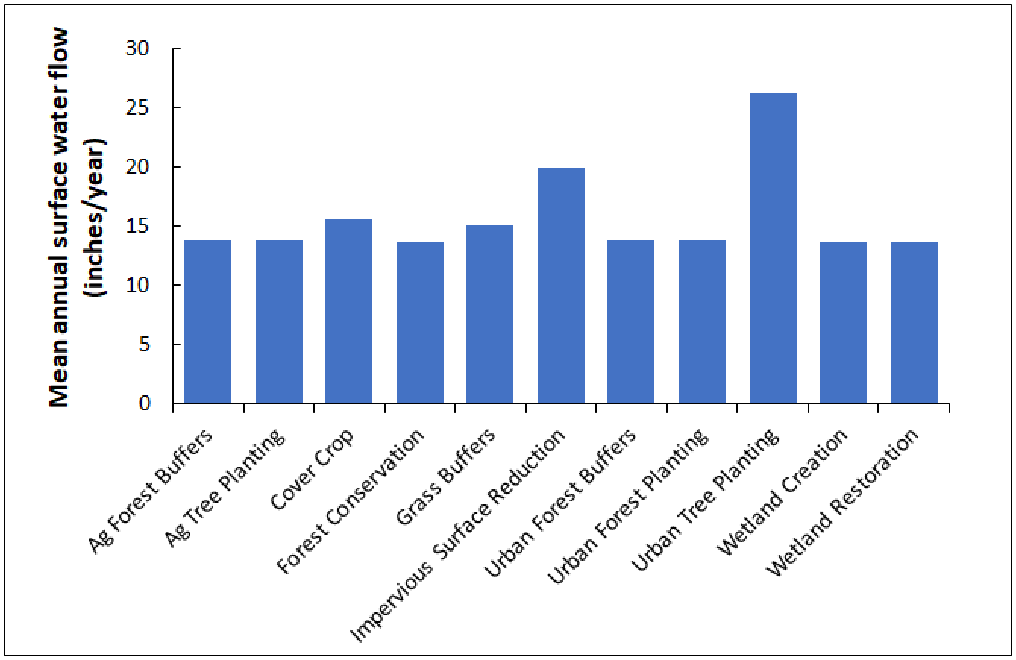


Figure 3.11.2. Annual water flow (in/yr) for different BMPs.

Additional Resources

Chesapeake Bay Program, 2020. Chesapeake Assessment and Scenario Tool (CAST) Version 2019. https://cast.chesapeakebay.net/Documentation/ModelDocumentation

Chapter 4. Watershed Outcomes

4.1. What are Watershed Outcomes?

The purpose of the Chesapeake Bay Watershed Agreement is to help guide the restoration of the watershed by setting mutual goals and tracking progress related to those goals, which helps hold signatories accountable. In 2014 a new Watershed Agreement was adopted and signed by 7 jurisdictions in the watershed, EPA for the federal government, and the tri-state Chesapeake Bay Commission that includes Maryland, Pennsylvania, and Virginia. The Watershed Agreement specifies 10 goals for sustainable fisheries, vital habitats, water quality, toxic contaminants, healthy watersheds, stewardship, land conservation, public access, environmental literacy, and climate resiliency (Chesapeake Bay Program, 2014). For each goal, there are measurable outcomes resulting in a total of 31 outcomes across all 10 goals.

4.1.1. Identifying Connections to Watershed Outcomes

We identified connections to most, but not all, of the 31 Watershed Agreement outcomes. In total, we identified connections to 16 out of 31 outcomes for the selected BMPs we present in this report. We limited connections and discussion of how BMPs may be related to watershed outcomes to those that had clear and simple explanations for direct and indirect connections. For example, we include Adaptation as an outcome because several BMPs we focus on (e.g., wetland restoration or forest buffers) contribute to flood control which is directly linked to the Adaptation outcome. We did not include Citizen Stewardship because while the BMPs may provide ecosystem services citizens are interested in, there was not a clear connection to the services provided resulting in increased citizen participation. See **Appendix B** for more on the difficulty of connecting certain outcomes to BMPs to shed light on why some outcomes are not highlighted in this report. We also include some outcomes that are more Bay focused (e.g., Oyster, Blue Crab Abundance, Fish habitat, SAV) because there were obvious connections between the BMPs we focused on and these Bay-centric outcomes (e.g., wetland restoration or creation may create fish habitat).

4.1.2. Watershed Outcome Factsheet Overview

For each Watershed Outcome, we have created a fact sheet that contains the following information:

- Outcome description
- Conceptual figure
- Importance of outcome
- Status of outcome
- BMPs (described in **Chapter 2**) and example ecosystem services that may contribute to the outcome
- Example of who benefits from the outcome

4.2. Adaptation

Description

Continually pursue, design and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms, and sea level rise.

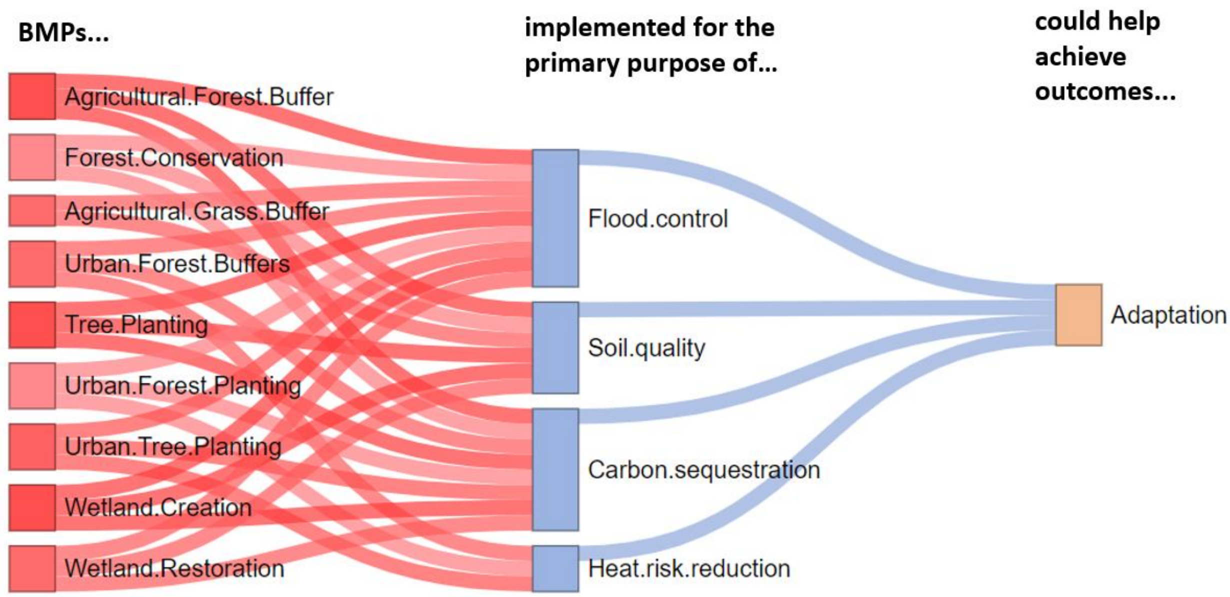


Figure 4.2.1. Examples of how Best Management Practices (red boxes) implemented for the primary purpose of providing ecosystem services such flood control, soil quality, carbon sequestration, and reducing extreme temperatures (blue boxes) may contribute to meeting the watershed outcome of Climate Adaptation (orange box).

Why does Adaptation matter?

The Chesapeake Bay and its watershed is susceptible to climate change driven impacts. Attaining this Watershed Agreement outcome will help communities throughout the watershed as they make plans to adapt to these changes and will likely help protect critical infrastructure susceptible to flooding and other impacts (Chesapeake Bay Program 2010).

What is the status of the Adaptation outcome?

As of 2018, recent progress for the Adaptation outcome was classified as “no change”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as habitat and flood control which may directly or indirectly contribute to meeting the Adaptation outcome (Fig. 4.2.1). Conservation and restoration BMPs implemented for the primary purpose of providing ecosystem services such flood control, soil quality, carbon sequestration, and reducing extreme temperatures may contribute to meeting the watershed outcome of Climate Adaptation

Additional Resources

Chesapeake Bay Program. 2010. Strategy for protecting and restoring the Chesapeake Bay Watershed. EPA-903-S-10-001. https://www.chesapeakebay.net/what/publications/strategy_for_protecting_and_restoring_the_chesapeake_bay_watershed_executiv

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.3. Black Duck Habitat

Description

By 2025, restore, enhance and preserve wetland habitats that support a wintering population of 100,000 black ducks, a species representative of the health of tidal marshes across the watershed. Refine population targets through 2025 based on best available science.

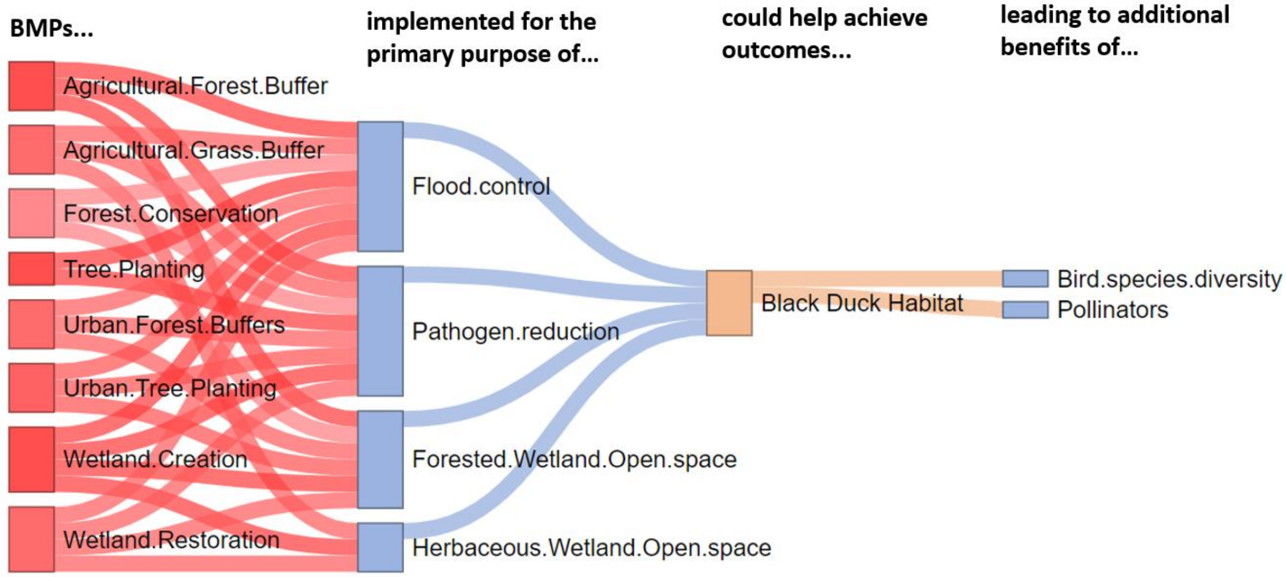


Figure 4.3.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes) such as flood control, pathogen reduction, and wetland habitat may contribute to meeting the watershed outcome of Black Duck Habitat (orange box). Actions to improve black duck habitat may in turn have unintended benefits for bird species diversity and pollinators (blue boxes, right) that share habitat with black ducks.

Why does the Black Duck Outcome matter?

Black ducks are an important indicator species that inform wetland health and food availability. Black duck abundance is especially important as an additional indicator for the wetland outcome because black ducks are dependent on wetland habitat so increases in black ducks is typically associated with increases in wetland habitat and/or wetland health.

What is the status of this outcome?

As of 2018, recent progress for the Black Duck outcome was classified as “increase”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as habitat and flood control which may directly or indirectly contribute to meeting the Black Duck outcome (Fig. 4.3.1). BMPs implemented to provide ecosystem services such as flood control, pathogen reduction, and wetland habitat may contribute to meeting the watershed outcome of Black Duck Habitat. Actions to improve black duck habitat may in turn have unintended benefits for bird species diversity and pollinators that share habitat with black ducks.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Black Duck outcome, various user groups may benefit. For example, residents and businesses benefit from flood control and hunters benefit from increased habitat for black ducks.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.4. Blue Crab Abundance

Description

Maintain a sustainable blue crab population based on the current 2012 target of 215 million adult females. Refine population targets through 2025 based on best available science.

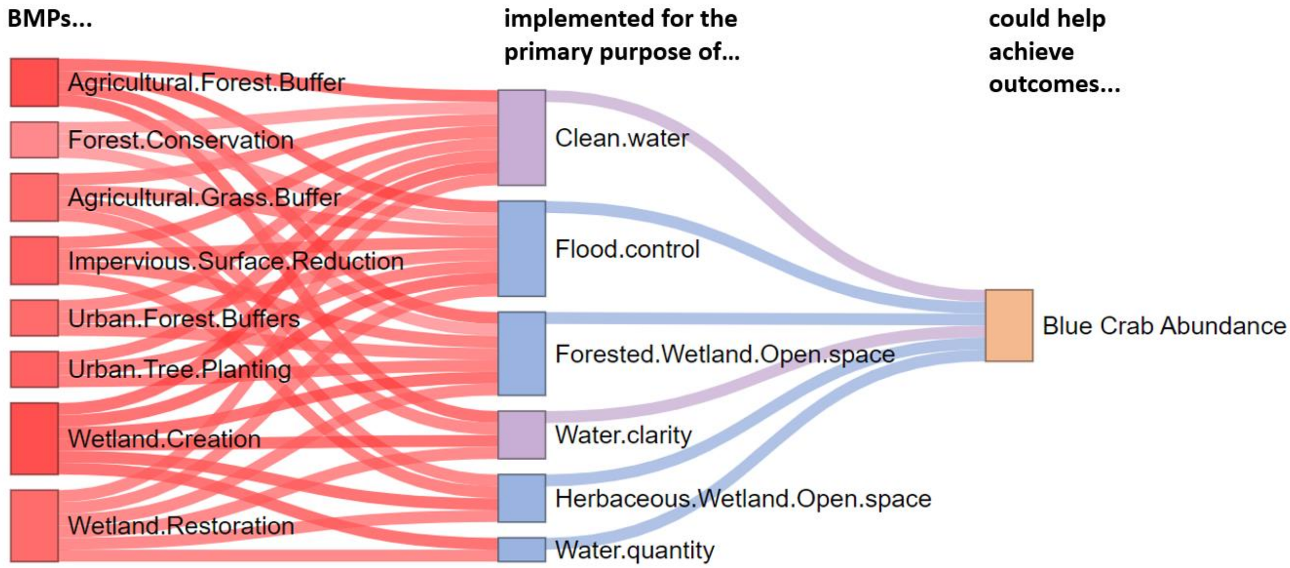


Figure 4.4.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes, quantified in this report) such as flood control, water quantity, wetland habitat, or water quality and clarity (purple boxes, not quantified) may contribute to meeting the watershed outcome of Blue Crab Abundance (orange box).

Why does the Blue Crab Abundance outcome matter?

Blue crabs, and other aquatic fauna, are an important fishery species both recreationally and commercially in the Chesapeake Bay. Improving the abundance of blue crab is important for a sustainable fishery which helps ensure the people of the Chesapeake Bay watershed can enjoy blue crab in the future. Additionally, blue crab can act as an indicator species for Bay health (Federal Leadership Committee for the Chesapeake Bay 2010).

What is the status of this outcome?

As of 2018, recent progress for the Blue Crab Abundance outcome was classified as “increase”. As of November 2021, this outcome has been classified as “on course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as habitat and flood control which may directly or indirectly contribute to meeting the Blue Crab Abundance outcome (Fig. 4.4.1). BMPs implemented to provide ecosystem services such as flood control, water quantity, wetland habitat, water quality, and water clarity may contribute to meeting the watershed outcome of Blue Crab Abundance.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

4.5. Brook Trout

Description

Restore and sustain naturally reproducing brook trout populations in Chesapeake headwater streams with an eight percent increase in occupied habitat by 2025.

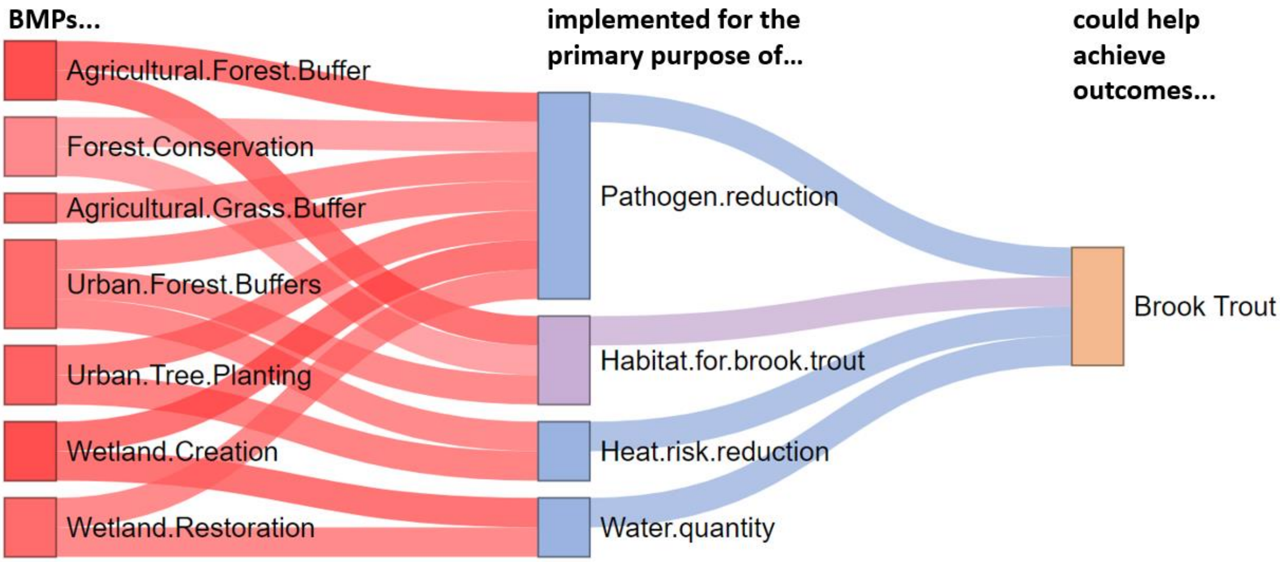


Figure 4.5.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes; quantified in this report) such as pathogen reduction, temperature regulation, water quantity, or habitat for brook trout (purple box; not quantified) may contribute to meeting the watershed outcome of Brook Trout (orange box).

Why does the Brook Trout outcome matter?

Brook trout are an important recreationally fished species throughout the watershed. They can act as an indicator for stream health because they are sensitive to temperature changes (Federal Leadership Committee for the Chesapeake Bay 2010).

What is the status of this outcome?

As of 2019, recent progress for the Brook Trout outcome was classified as "no change". As of November 2021, this outcome has been classified as "off course". See Chesapeake Progress for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as reduced water temperature and pathogen reduction which may indirectly contribute to meeting the Brook Trout outcome (Fig. 4.5.1). BMPs implemented to provide ecosystem services such as pathogen reduction, temperature regulation, water quantity, or habitat for brook trout may contribute to meeting the watershed outcome of Brook Trout.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Brook Trout outcome, different user groups may benefit. For example, anglers may benefit from reduced stream temperatures and pathogen reduction.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.6. Fish Habitat

Description

Continually improve effectiveness of fish habitat conservation and restoration efforts by identifying and characterizing critical spawning, nursery and forage areas within the Bay and tributaries for important fish and shellfish, and use existing and new tools to integrate information and conduct assessments to inform restoration and conservation efforts.

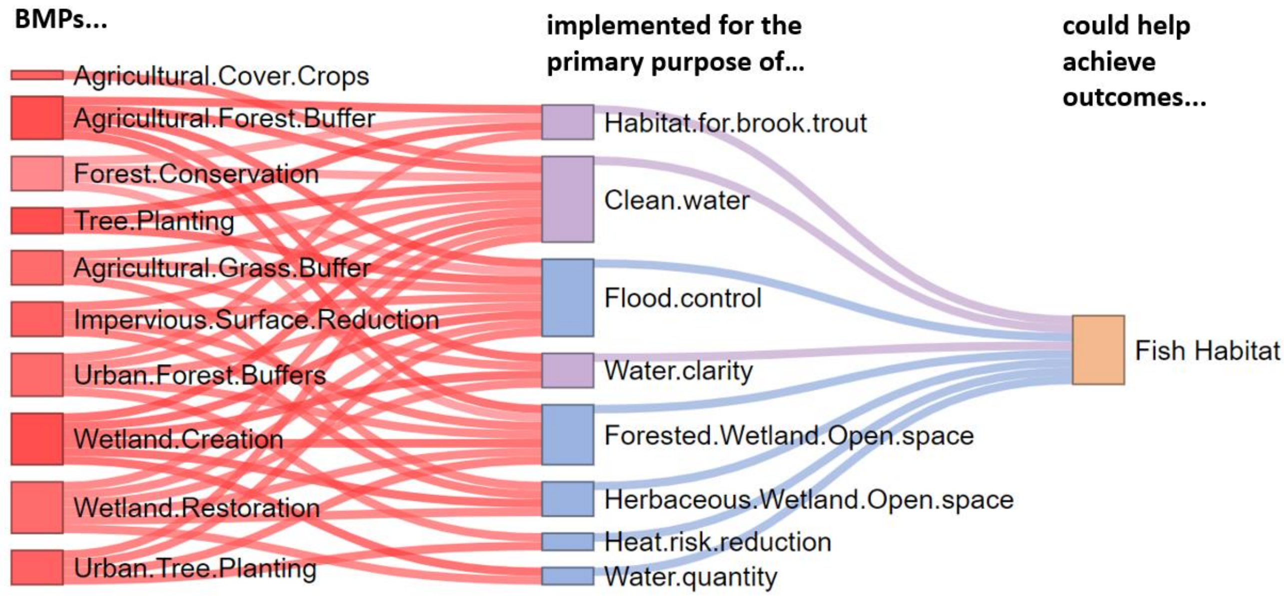


Figure 4.6.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes; quantified in this report) such as flood control, temperature regulation, water quantity, and wetland habitat, or clean water and habitat for brook trout (purple box; not quantified) may contribute to meeting the watershed outcome of Fish Habitat (orange box).

Why does the Fish Habitat outcome matter?

The fish habitat outcome is important because the Chesapeake Bay is an important fisheries production region on the East Coast. Improving conservation of fish habitat is important for many recreational and commercial species such as shad, striped bass, and flounder (Federal Leadership Committee for the Chesapeake Bay 2010).

What is the status of this outcome?

As of 2018, recent progress for the Fish Habitat outcome was classified as "increase". As of November 2021, this outcome has been classified as "on course". See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as reduced water temperature and habitat for fish which may indirectly or directly contribute to meeting the Fish Habitat outcome (Fig. 4.6.1). BMPs implemented to provide ecosystem services such as flood control, temperature regulation, water quantity, and wetland habitat, or clean water and habitat for brook trout may contribute to meeting the watershed outcome of Fish Habitat.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Fish Habitat outcome, various user groups may benefit. For example, anglers may benefit from reduced water temperatures and residents may benefit from improved flood control.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.7. Forest Buffer

Description

Continually increase the capacity of forest buffers to provide water quality and habitat benefits throughout the watershed. Restore 900 miles per year of riparian forest buffer and conserve existing buffers until at least 70 percent of riparian areas throughout the watershed are forested.

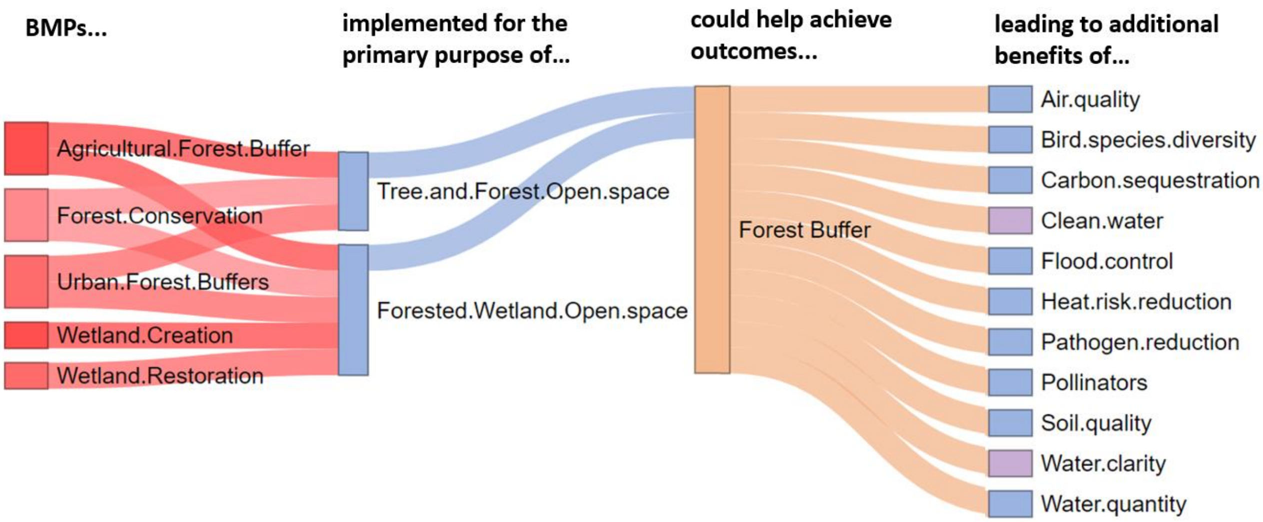


Figure 4.7.1. Best Management Practices (red boxes) implemented to conserve and create acres of forest space (blue boxes) contribute to meeting the Forest Buffer watershed outcome (orange box). Achievement of the Forest Buffer outcome in turn could lead to additional ecosystem services benefits (blue/purple boxes, right) provided by forests.

Why does the Forest Buffer outcome matter?

Forest buffers are important because they restore riparian forest which can improve streambank stabilization and reduce erosion, provide habitat, and provide shade which can reduce stream temperatures. (Federal Leadership Committee for the Chesapeake Bay 2010).

What is the status of this outcome?

As of 2018, recent progress for the Forest Buffer outcome was classified as “decrease”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs directly provide forest buffers (e.g., forest buffer BMPs) or provide ecosystem services that improve general habitat quality (Fig. 4.7.1). BMPs implemented to conserve and create acres of forest space may contribute to meeting the Forest Buffer watershed outcome. Achievement of the Forest Buffer outcome in turn could lead to additional ecosystem services benefits provided by forests.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.8. Healthy Watersheds

Description

100 percent of state-identified currently healthy waters and watersheds remain healthy by 2025.

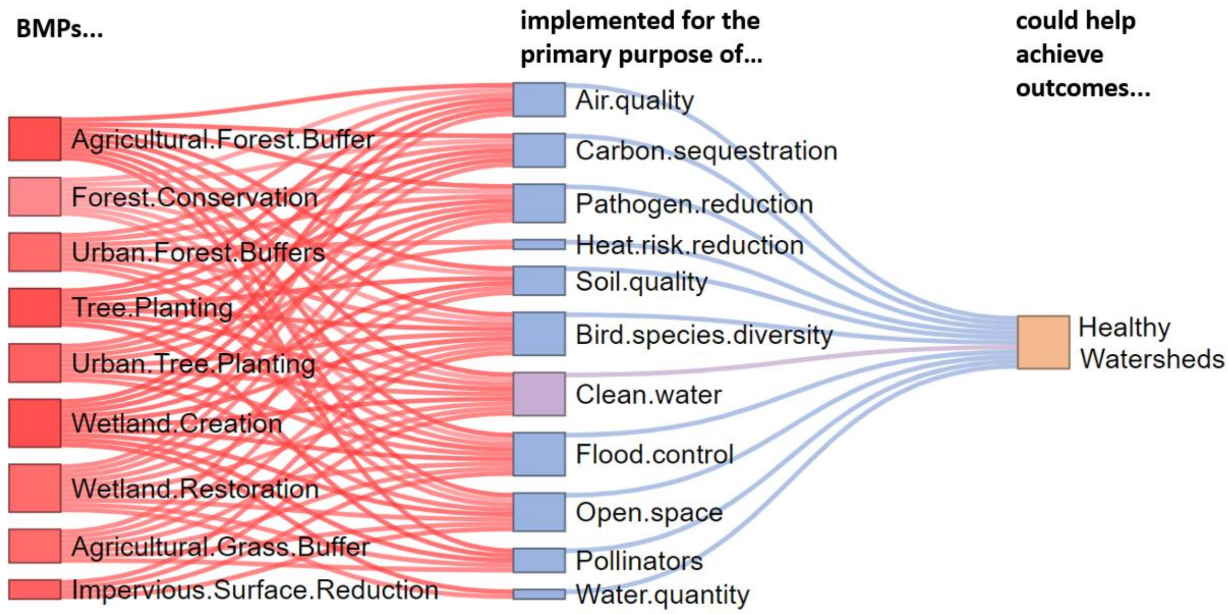


Figure 4.8.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes, quantified this report) such as flood control, pathogen reduction, pollinators, bird diversity, or clean water (purple box, not quantified) among others, may contribute to meeting the watershed outcome of Healthy Watersheds (orange box).

Why does the Healthy Watersheds outcome matter?

Maintaining healthy watersheds is important because doing so maintains existing benefits from those watersheds like clean water and critical habitat. This outcome is also important because protecting already healthy streams is less expensive than restoring impaired waters.

What is the status of this outcome?

As of 2018, recent progress for the Healthy Watersheds outcome was classified as “no change”. As of November 2021, this outcome has been classified as “uncertain”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as reduced air temperature and flood control which may indirectly or directly contribute to meeting the Healthy Watersheds outcome (Fig. 4.8.1). BMPs implemented to provide ecosystem services such as flood control, pathogen reduction, pollinators, bird diversity, or clean water among others, may contribute to meeting the watershed outcome of Healthy Watersheds.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Healthy Watersheds outcome, various user groups may benefit. For example, anglers may benefit from reduced water temperatures and residents may benefit from improved flood control.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.9. Oyster

Description

Continually increase finfish and shellfish habitat and water quality benefits from restored oyster populations. Restore native oyster habitat and populations in 10 tributaries by 2025 and ensure their protection.

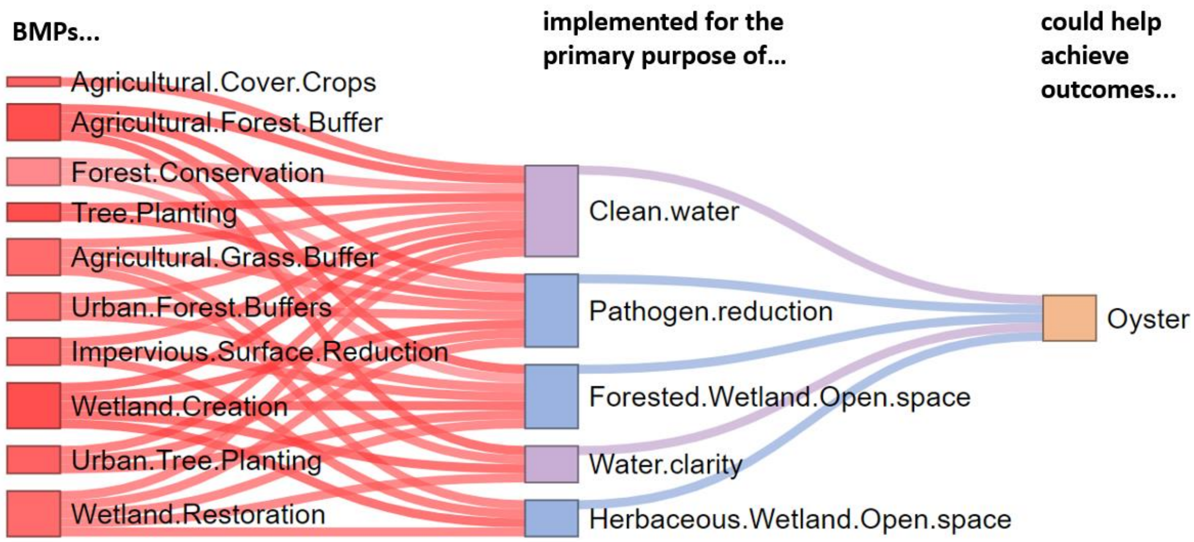


Figure 4.9.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes; quantified in this report) such as pathogen reduction, wetland habitat, or water quality and clarity (purple boxes; not quantified) may contribute to meeting the watershed outcome of Oyster habitat (orange box).

Why does the Oyster outcome matter?

Oysters, and other aquatic fauna, are an important fishery species both recreationally and commercially in the Chesapeake Bay. Oysters act as an indicator species for Bay health and are also important for water filtration (Federal Leadership Committee for the Chesapeake Bay 2010).

What is the status of this outcome?

As of 2018, recent progress for the Oyster outcome was classified as “increase”. As of November 2021, this outcome has been classified as “on course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as habitat for oyster and pathogen reduction which may indirectly or directly contribute to meeting the Oyster outcome (Fig. 4.9.1). BMPs implemented to provide ecosystem services such as pathogen reduction, wetland habitat, or water quality and clarity may contribute to meeting the watershed outcome of Oyster habitat.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Oyster outcome, various user groups may benefit. For example, anglers may benefit from water clarity.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.10. Protected Lands

Description

By 2025, protect an additional two million acres of lands throughout the watershed—currently identified as high conservation priorities at the federal, state or local level—including 225,000 acres of wetlands and 695,000 acres of forest land of highest value for maintaining water quality (2010 baseline year).

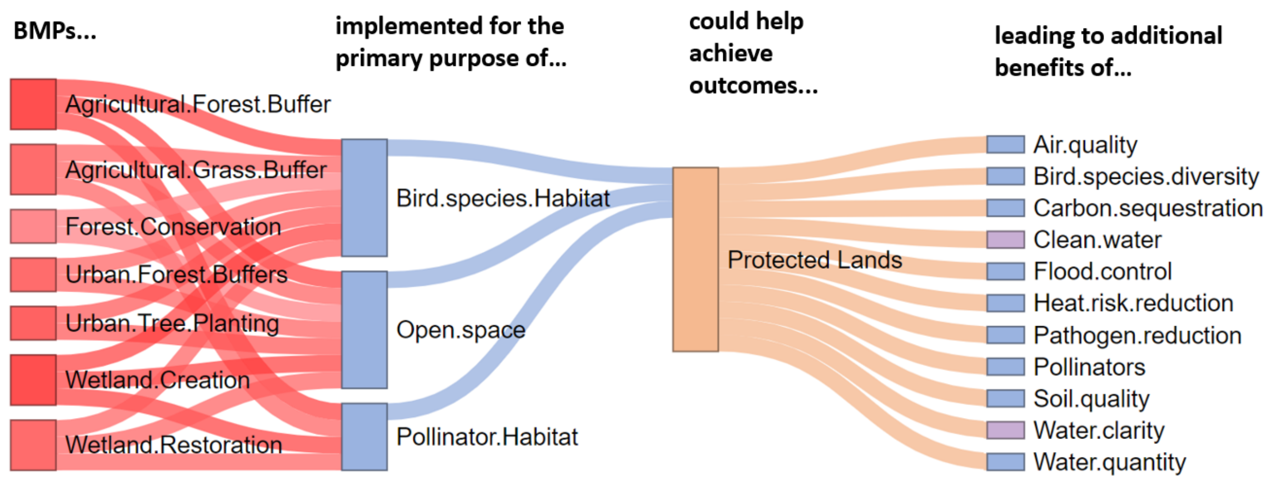


Figure 4.10.1. Best Management Practices (red boxes) implemented to create acres of forest, wetland, bird habitat, or pollinator habitat (blue boxes) may contribute to meeting the Protected Lands watershed outcome (orange box). Achievement of the Protected Lands outcome in turn could lead to additional ecosystem services benefits (blue/purple boxes, right) provided by these habitats.

Why does the Protected Lands outcome matter?

Protected lands are important because of the ecological, cultural, historical, economic, and recreational importance of lands throughout the Chesapeake Bay Watershed. Increasing protection of these lands preserves the benefits to people and communities throughout the watershed.

What is the status of this outcome?

As of 2018, recent progress for the Protected lands outcome was classified as "increase". As of November 2021, this outcome has been classified as "on course". See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as habitat for birds and greenspace which may indirectly or directly contribute to meeting the Protected lands outcome (Fig. 4.10.1). BMPs implemented to create acres of forest, wetland, bird habitat, or pollinator habitat may indirectly contribute to meeting the Protected Lands watershed outcome, if paired with policy decisions to identify them as protected or priority conservation lands. Achievement of the Protected Lands outcome in turn could lead to additional ecosystem services benefits provided by these habitats.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Protected lands outcome, various user groups may benefit. For example, residents may benefit from increased green space.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.11. Public Access Site Development

Description

By 2025, add 300 new public access sites, with a strong emphasis on providing opportunities for boating, swimming, and fishing, where feasible. (2010 baseline year)

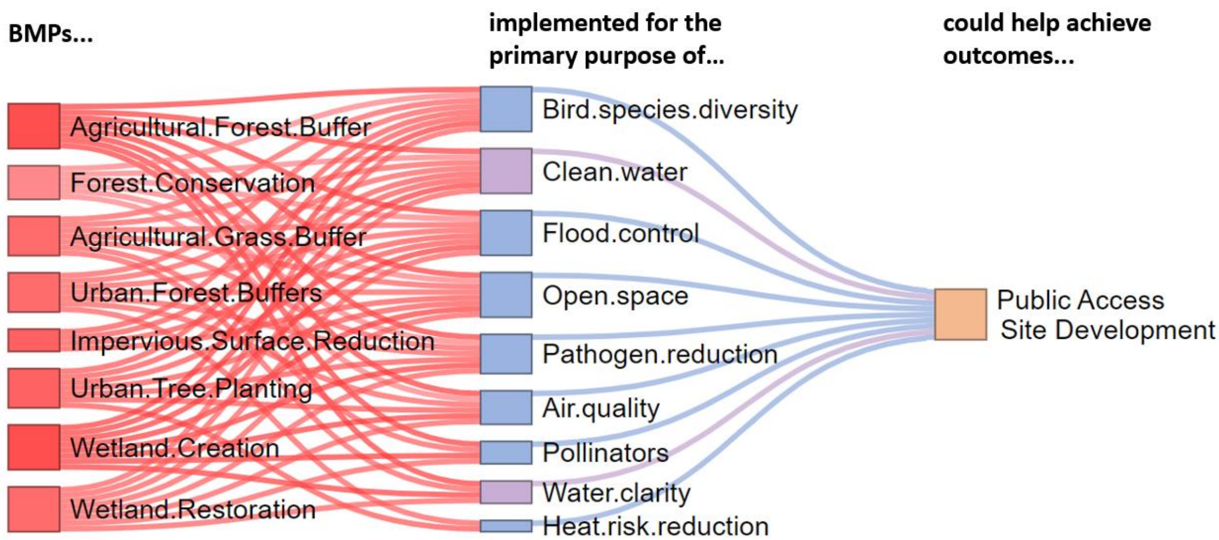


Figure 4.11.1. Best Management Practices (red boxes) implemented to improve bird and pollinator diversity, control flooding, create open space, regulate air quality and air temperatures, reduce water-borne pathogens (blue boxes, quantified this report) or improve water clarity and quality (purple boxes, not quantified) may contribute to meeting the Public Access watershed outcome (orange box) by helping to create conditions favorable and safe for public activities.

Why does the Public Access Site outcome matter?

Public access site development is important because of the ecological, cultural, historical, economic, and recreational important of lands throughout the Chesapeake Bay Watershed. Increasing public access to these lands benefits the people and communities throughout the watershed.

What is the status of this outcome?

As of 2018, recent progress for the Public Access Site Development outcome was classified as “increase”. As of November 2021, this outcome has been classified as “on course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as green space and pathogen reduction which may indirectly or directly contribute to meeting the Public Access Site Development outcome (Fig. 4.11.1). BMPs implemented to improve bird and pollinator diversity, control flooding, create open space, regulate air quality and air temperatures, reduce water-borne pathogens, or improve water clarity and quality may indirectly contribute to meeting the Public Access watershed outcome by helping to create conditions favorable and safe for public activities.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Public Access Site Development outcome, various user groups may benefit. For example, residents may benefit from increased green space and anglers may benefit from pathogen reduction.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.12. Stream Health

Description

Continually improve stream health and function throughout the watershed. Improve health and function of ten percent of stream miles above the 2008 baseline for the Chesapeake Bay watershed.

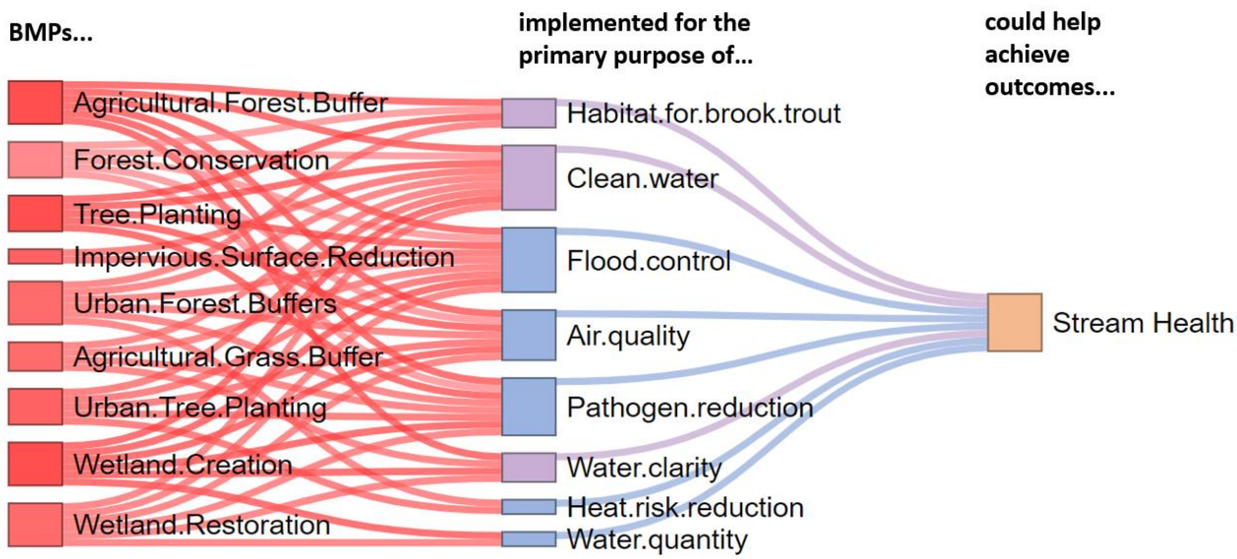


Figure 4.12.1. Best Management Practices (red boxes) implemented to improve ecosystem services (blue boxes, quantified in this report) flood control, water quantity, mitigate extreme temperatures, reduce pathogens and atmospheric deposition of pollutants bird and pollinator diversity, control flooding, create open space, regulate air quality and air temperatures, or provide clean water and improve habitat for brook trout (purple boxes, not quantified) may contribute to meeting the Stream Health watershed outcome (orange box).

Why does the Stream Health outcome matter?

Stream health is important because improving stream health throughout the watershed will benefit the Bay by reducing nutrients, sediments, and contaminants from being deposited into the Bay.

What is the status of this outcome?

As of 2018, recent progress for the Stream Health outcome was classified as “no change”. As of November 2021, this outcome has been classified as “uncertain”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as reduced air and water temperature and pathogen reduction which may indirectly or directly contribute to meeting the Stream Health outcome (Fig. 4.12.1). BMPs implemented to improve ecosystem services flood control, water quantity, mitigate extreme temperatures, reduce pathogens and atmospheric deposition of pollutants bird and pollinator diversity, control flooding, create open space, regulate air quality and air temperatures, or provide clean water and improve habitat for brook trout may contribute to meeting the Stream Health watershed outcome.

Who benefits from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Stream Health outcome, various user groups may benefit. For example, residents and anglers may benefit from reduced air and stream temperatures.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.13. Submerged Aquatic Vegetation (SAV)

Description

Sustain and increase the habitat benefits of SAV (underwater grasses) in the Chesapeake Bay. Achieve and sustain the ultimate outcome of 185,000 acres of SAV Bay-wide necessary for a restored Bay. Progress toward this ultimate outcome will be measured against a target of 90,000 acres by 2017 and 130,000 acres by 2025.

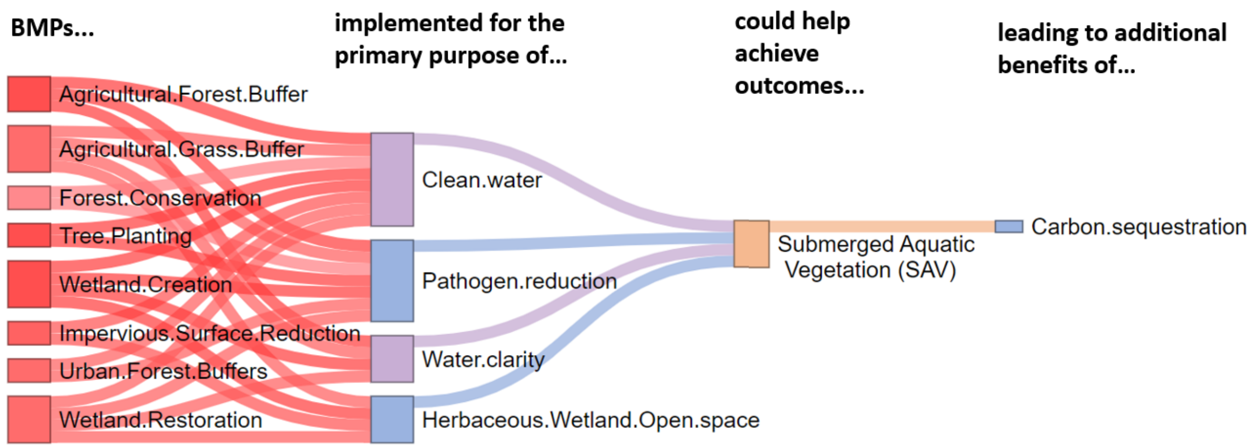


Figure 4.13.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes; quantified in this report) such as pathogen reduction, wetland habitat, or improve water clarity and quality (purple boxes; not quantified) may contribute to meeting the watershed outcome of SAV (orange box), which in turn can help to sequester carbon.

Why does the SAV Outcome matter?

Submerged aquatic vegetation is considered a critical priority habitat in tidal waters for numerous aquatic species (Federal Leadership Committee for the Chesapeake Bay 2010), and for storing organic matter or 'blue carbon' as part of a climate adaptation strategy (Chesapeake Bay Progress 2022).

What is the status of this outcome?

An estimated 60% of segments are expected to meet water quality standards for underwater grasses (SAV) in the bay and tidal tributaries by 2025 (Federal Leadership Committee for the Chesapeake Bay 2010).

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as water clarity and pathogen reduction which may indirectly or directly contribute to meeting the SAV outcome. (Fig. 4.13.1). BMPs implemented to provide ecosystem services such as pathogen reduction, wetland habitat, or improve water clarity and quality may contribute to meeting the watershed outcome of SAV, which in turn can help to sequester carbon.

Who may benefit from this outcome?

By implementing BMPs that provide ecosystem services to help meet the SAV outcome, various user groups may benefit. For example, residents benefit from improved water clarity.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Federal Leadership Committee for the Chesapeake Bay. Executive order 13508: Strategy for protecting and restoring the Chesapeake Bay Watershed. 12 May 2010. EPA number: 903R10003

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.14. Toxic Contaminants Policy and Prevention

Description

Continually improve practices and controls that reduce and prevent the effects of toxic contaminants below levels that harm aquatic systems and humans. Build on existing programs to reduce the amount and effects of PCBs in the Bay and watershed. Use research findings to evaluate the implementation of additional policies, programs and practices for other contaminants that need to be further reduced or eliminated.

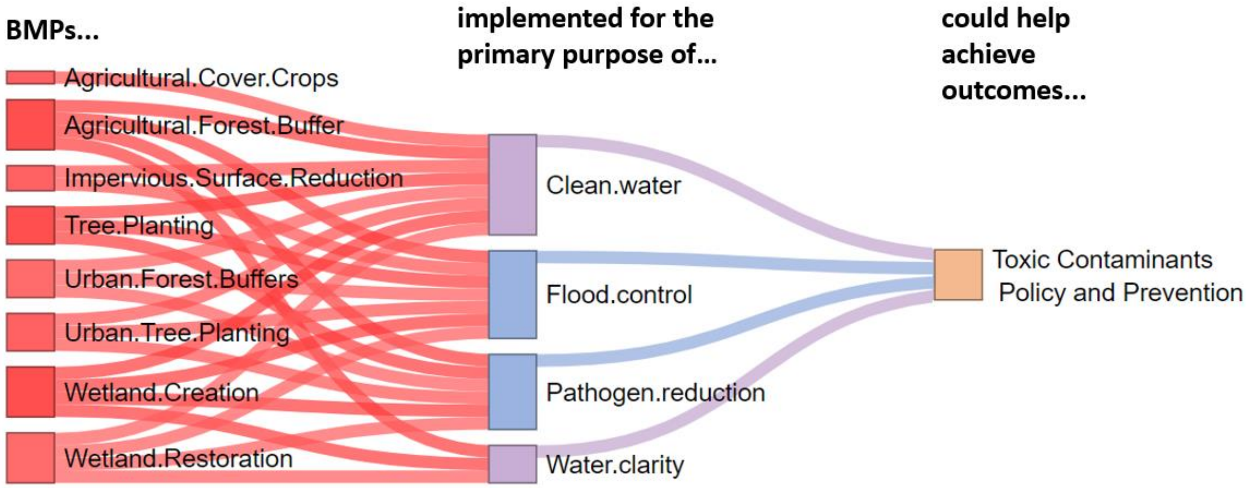


Figure 4.14.1. Best Management Practices (red boxes) implemented to provide ecosystem services (blue boxes; quantified in this report) that reduce pathogens and human contact with flood waters, or improve water clarity and quality (purple boxes; not quantified) may contribute to meeting the watershed outcome of Toxic Contaminants Policy and Prevention (orange box).

Why does Toxic Contaminants Policy and Prevention matter?

Tracking and reducing toxic contaminants in waterways benefits humans as it reduces their risk to potentially deleterious diseases. It also benefits aquatic life, including the many species humans enjoy harvesting recreationally or commercially. Reducing toxic contaminants from entering waterways can also help improve fisheries by reducing exposure of fish or oysters to toxics that would prevent them from being harvested and sold.

What is the status of this outcome?

As of 2018, recent progress for the Toxic Contaminants Policy and Prevention outcome was classified as “decrease”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs provide ecosystem services such as water clarity and flood control which may indirectly contribute to meeting the Toxic Contaminants Policy and Prevention outcome. (Fig. 4.14.1). BMPs implemented to provide ecosystem services that reduce pathogens and human contact with flood waters, or improve water clarity and quality may indirectly contribute to meeting the watershed outcome of Toxic Contaminants Policy and Prevention.

Who may benefit from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Toxic Contaminants Policy and Prevention outcome, various user groups may benefit. For example, residents benefit from flood control.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.15. Tree Canopy

Description

Continually increase urban tree canopy capacity to provide air quality, water quality and habitat benefits throughout the watershed. Expand urban tree canopy by 2,400 acres by 2025. Here, urban tree canopy is broadly defined as tree plantings in communities of any size that are not on agricultural lands.

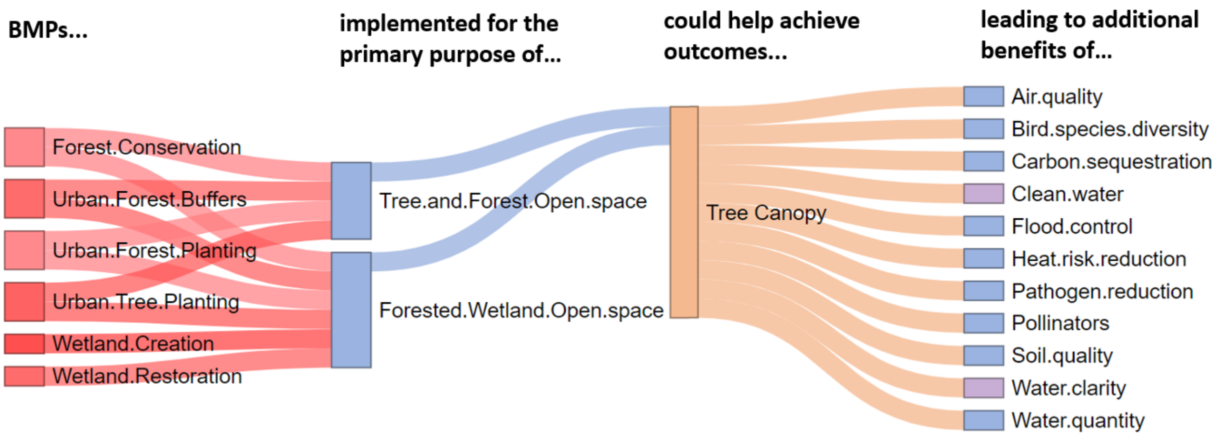


Figure 4.15.1. Best Management Practices (red boxes) implemented to plant trees and create forest habitat (blue boxes) contribute to meeting the Tree Canopy watershed outcome (orange box). Achievement of the Tree Canopy outcome in turn could lead to additional ecosystem services benefits (blue/purple boxes, right) provided by trees and forests.

Why does the Tree Canopy outcome matter?

Tree canopy is important in urban areas because it provides capacity for air quality, water quality and habitat improvements.

What is the status of this outcome?

As of 2018, recent progress for the Tree Canopy outcome was classified as “no change”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs either directly contribute to the Tree Canopy outcome (e.g., urban tree planting) or provide ecosystem services that benefit trees. (Fig. 4.15.1). BMPs implemented to plant trees and create forest habitat could contribute to meeting the Tree Canopy watershed outcome. Achievement of the Tree Canopy outcome in turn could lead to additional ecosystem services benefits provided by trees and forests.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.16. Wetlands

Description

Continually increase the capacity of wetlands to provide water quality and habitat benefits throughout the watershed. Create or reestablish 85,000 acres of tidal and non-tidal wetlands and enhance the function of an additional 150,000 acres of degraded wetlands by 2025. These activities may occur in any land use (including urban) but primarily occur in agricultural or natural landscapes.

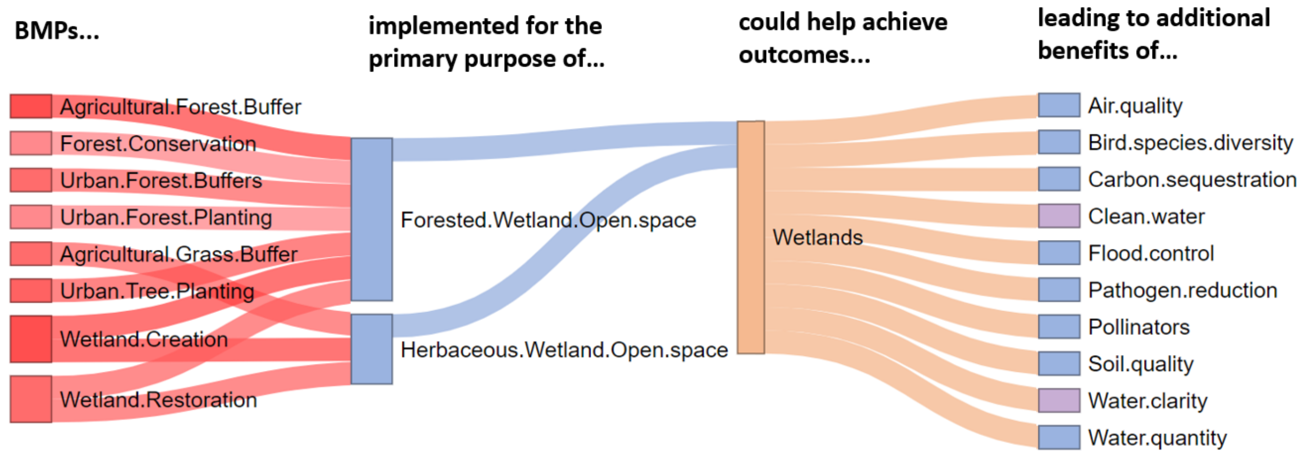


Figure 4.16.1. Best Management Practices (red boxes) implemented to restore and create wetland habitat (blue boxes) contribute to meeting the Wetland watershed outcome (orange box). Achievement of the Wetland outcome in turn could lead to additional ecosystem services benefits (blue/purple boxes, right) provided by wetlands.

Why do Wetlands matter?

Restoring habitat throughout the Chesapeake Bay Watershed is important, and wetlands are one habitat that provides many resources for many species, including humans. Wetlands provide many ecosystem services ranging from water filtration to reducing coastal storm surge and providing habitat for commercially valuable fauna such as blue crab and black duck.

What is the status of this outcome?

As of 2018, recent progress for the Wetlands outcome was classified as “increase”. As of November 2021, this outcome has been classified as “off course”. See Chesapeake Progress 2022 for more information.

What BMPs contribute to this outcome?

BMPs directly contribute to the Wetlands outcome (e.g., wetland restoration) or provide ecosystem services which may indirectly or directly contribute to meeting the Wetlands outcome. (Fig. 4.16.1). BMPs implemented to restore and create wetland habitat could contribute to meeting the Wetland watershed outcome. Achievement of the Wetland outcome in turn could lead to additional ecosystem services benefits provided by wetlands.

Who may benefit from this outcome?

By implementing BMPs that provide ecosystem services to help meet the Wetlands outcome, various user groups may benefit. For example, residents benefit from flood control.

Additional Resources

Chesapeake Progress 2022. https://www.chesapeakeprogress.com/climate-change/climate-adaptation

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

4.17. 2025 Watershed Implementation Plans (WIP) Outcome

Description

By 2025, have all practices and controls installed to achieve the Bay's dissolved oxygen, water clarity/submerged aquatic vegetation and chlorophyll *a* standards as articulated in the Chesapeake Bay TMDL document.

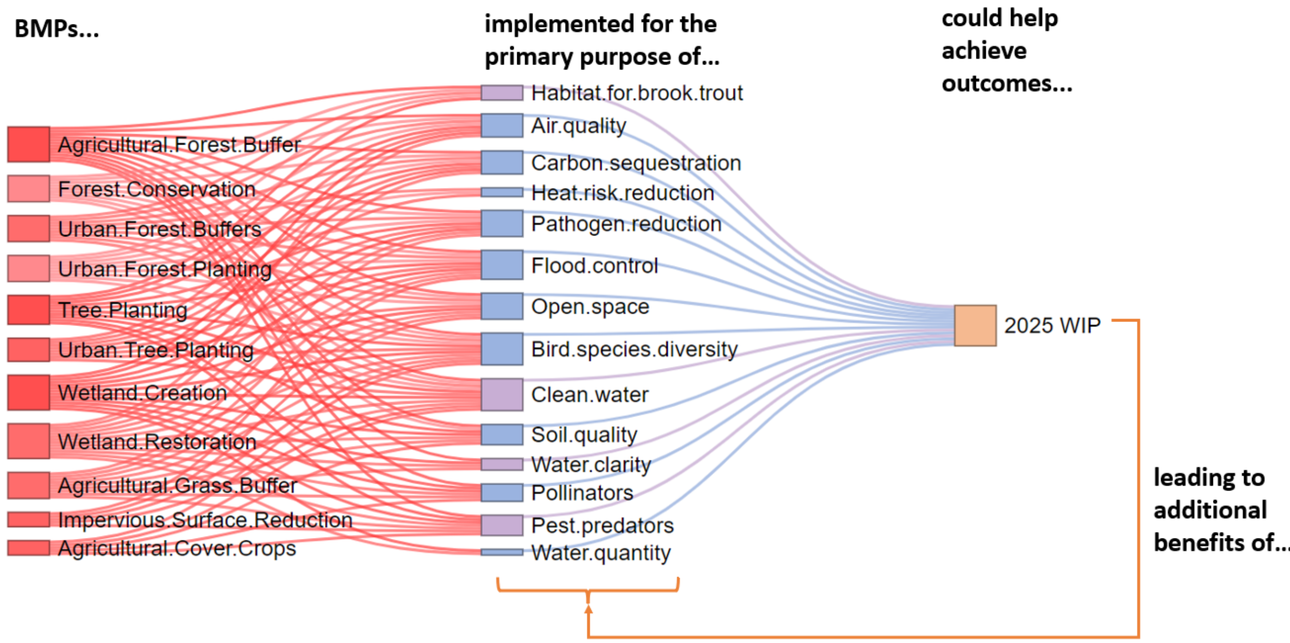


Figure 4.17.1. Best Management Practices (red boxes) implemented to improve water clarity or clean water, or for other reasons such as to achieve other ecosystem services (blue boxes, quantified in this report; purple boxes, not quantified) not related to TMDL requirements, such as improving air quality or bird diversity, contribute to meeting the 2025 WIP watershed outcome (orange box). Achievement of the 2025 WIP outcome in turn could lead to additional ecosystem benefits, even if not the direct target of BMP implementation.

Why does the 2025 WIP matter?

The Chesapeake Bay TMDL requires nutrient and sediment reductions and watershed implementation plans (WIPS) layout the actions that jurisdictions within the Bay will take to achieve the water quality standards required by the TMDL. The 2025 WIP outline actions each jurisdiction will implement to meet the restoration goals between 2019 and 2025.

What BMPs contribute to this outcome?

BMPs are implemented in order to meet the TMDL, so all BMPs included in this report, and all BMPs recommended to meet the TMDL would contribute to meeting the 2025 WIP outcome. BMPs implemented to improve water clarity or clean water, or for other reasons not directly related to TMDL requirements, such as create pollinator habitat, bird habitat, or buffer air pollution, could contribute to meeting the 2025 WIP watershed outcome. Achievement of the 2025 WIP outcome in turn could lead to additional ecosystem benefits, even if not the direct target of BMP implementation.

Additional Resources

Chesapeake Bay Program. 2010. Strategy for protecting and restoring the Chesapeake Bay Watershed. EPA-903-S-10-001. https://www.chesapeakebay.net/what/publications/strategy_for_protecting_and_restoring_the_chesapeake_bay_watershed_executiv

Tetra Tech, Inc. 2017. Estimation of BMP Impact on Chesapeake Bay Program Management Strategies. Fairfax VA.

Chapter 5. Summary and Future Directions

5.1. Summary

Here we share information on the connections between BMPs, Ecosystem Services, and Watershed Outcomes for a select number of BMPs that were lagging in implementation, associated with habitat restoration or creation and relevant to upstream communities. We scoped BMPs and Ecosystem Services with CBP partners and created individual fact sheets for every BMP, Watershed Outcome and Ecosystem service. We provide current estimates of ecosystem service supply for the watershed for 10 ecosystem services and detail how the selected BMPs may influence the supply of those services depending on the number of acres implemented.

5.1.1. How can this information be used?

We have intentionally organized the report into fact sheets so that this information can be built on by communication and outreach specialists in the watershed and we intend for these fact sheets to be the first step in using this information. In addition, estimates of the select ecosystem services will be incorporated into Chesapeake Bay Program tools. For example, estimates of ecosystem services provided by select BMPs can be incorporated into CAST (https://cast.chesapeakebay.net/) so that users will receive a report on how BMP scenarios not only impact nitrogen, phosphorous, and sediment reductions, but also a select number of ecosystem services. Additionally, estimates of current ecosystem service supply for the watershed can be integrated with other existing tools such as:

- Watershed Data Dashboard: https://gis.chesapeakebay.net/wip/dashboard/
- Geographic Targeting Portal: https://gis.chesapeakebay.net/targeting/
- Chesapeake Bay Environmental Justice and Equity Dashboard: https://gis.chesapeakebay.net/diversity/dashboard/
- The Eco-Health Relationship Browser: https://cast.chesapeakebay.net/ecohealth/index

This will allow users to get a sense of hot and cold spots of ecosystem service supply and consider whether they want to prioritize BMPs or other management actions in areas with fewer ecosystem services.

5.1.2. Next steps

This report builds on previous work (e.g., Tetra Tech, 2017) by quantifying ecosystem services, in addition to identifying connections between BMPs, ecosystem services, and watershed outcomes. There are many additional steps that can be taken to build on this work (and the work that came before it), and ultimately to fully integrate ecosystem services information into policies and management actions that improve progress toward achieving habitat and living resource watershed goals (Rossi et al. 2022b, 2023). For example, most of the methods to quantify ecosystem service supply in this report are based on remotely sensed data and are therefore broader and not specific to a certain location, although we chose to focus at a county scale. Future work could be completed to update the quantification methods or metrics used in this report to be more location specific (e.g., on the ground field data), to be applied to finer spatial scales, updated as newer data becomes available, or modified to adjust to alternative landcover classifications. Additionally, quantification of more ecosystem services could be completed to expand this short list of FEGS.

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Appendix A. Ecosystem Services Quantification Methods

A1. Land Cover

Approach

To maintain compatibility with tools used by the Chesapeake Bay Program and their partners, we based our ecosystem services analysis on the Chesapeake Bay Conservancy 1 meter resolution 2013/2014 land use land cover maps in the Chesapeake Bay Assessment Scenario Tool (CAST; https://cast.chesapeakebay.net/). In general, we assumed each of our target BMPs would result in new acres of landcover (e.g., natural tree canopy, wetland), and reviewed literature to assemble values of FEGS supply by landcover type, reviewed existing models to translate landcover into FEGS supply, or used available data to generate statistical relationships between known acres of landcover and observed measures of ecosystem services.

Because many BMP land covers were not explicitly mapped in the Chesapeake Bay Conservancy LULC data (e.g., forest, cover crops), we compared maps from the 2016 National Land Cover Database (NLCD) to identify the landcover which best represented the BMP (Fig. A1.1). Crops and pasture in NLCD, for example, predominantly mapped onto low vegetation in the Chesapeake Bay data (Fig. A1.2). Rural or agricultural forest in NLCD predominantly mapped onto natural tree canopy in CAST, whereas tree canopy over impervious surfaces or roads in CAST was predominantly associated with urban (or developed) areas in NLCD. Wetlands in CAST were predominantly associated with emergent herbaceous wetlands in NLCD, with less than 18% of wetland area associated with woody wetlands.

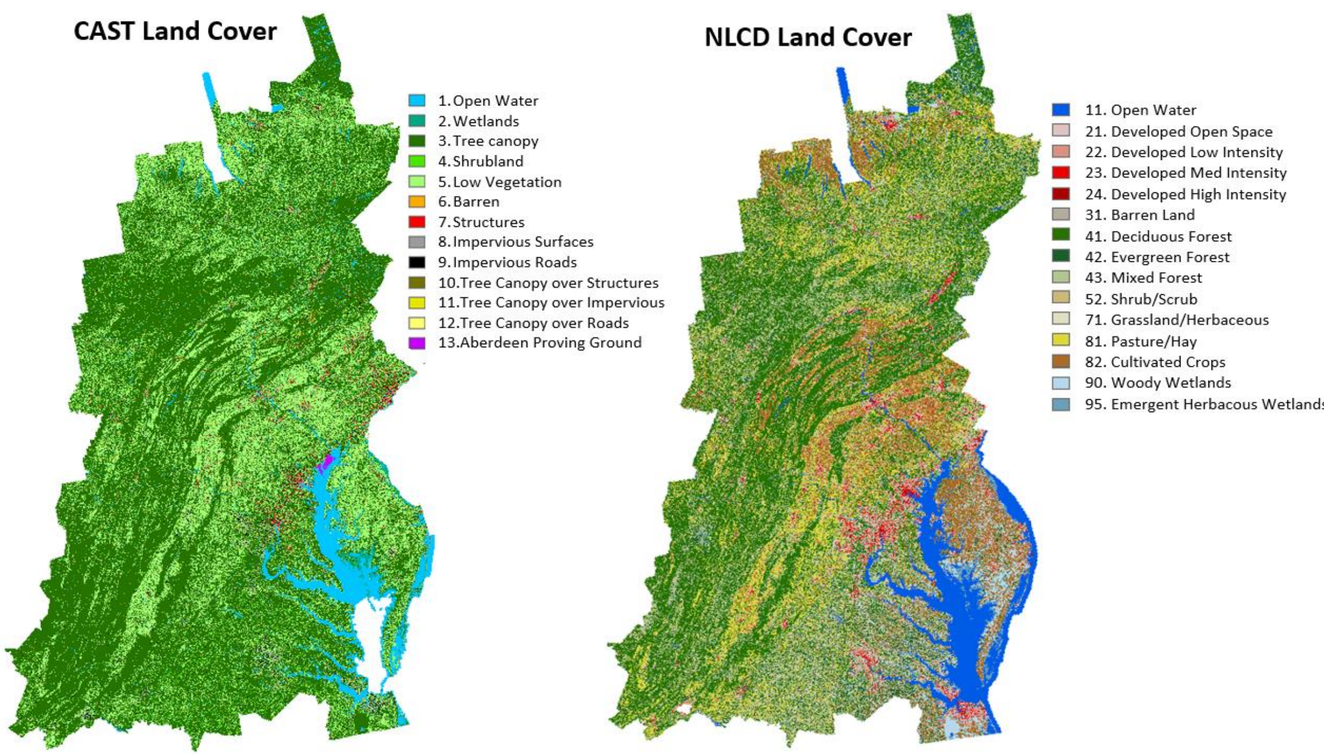

Figure A1.1. Comparison of landcover maps from 2013/2014 CAST and 2016 NLCD.

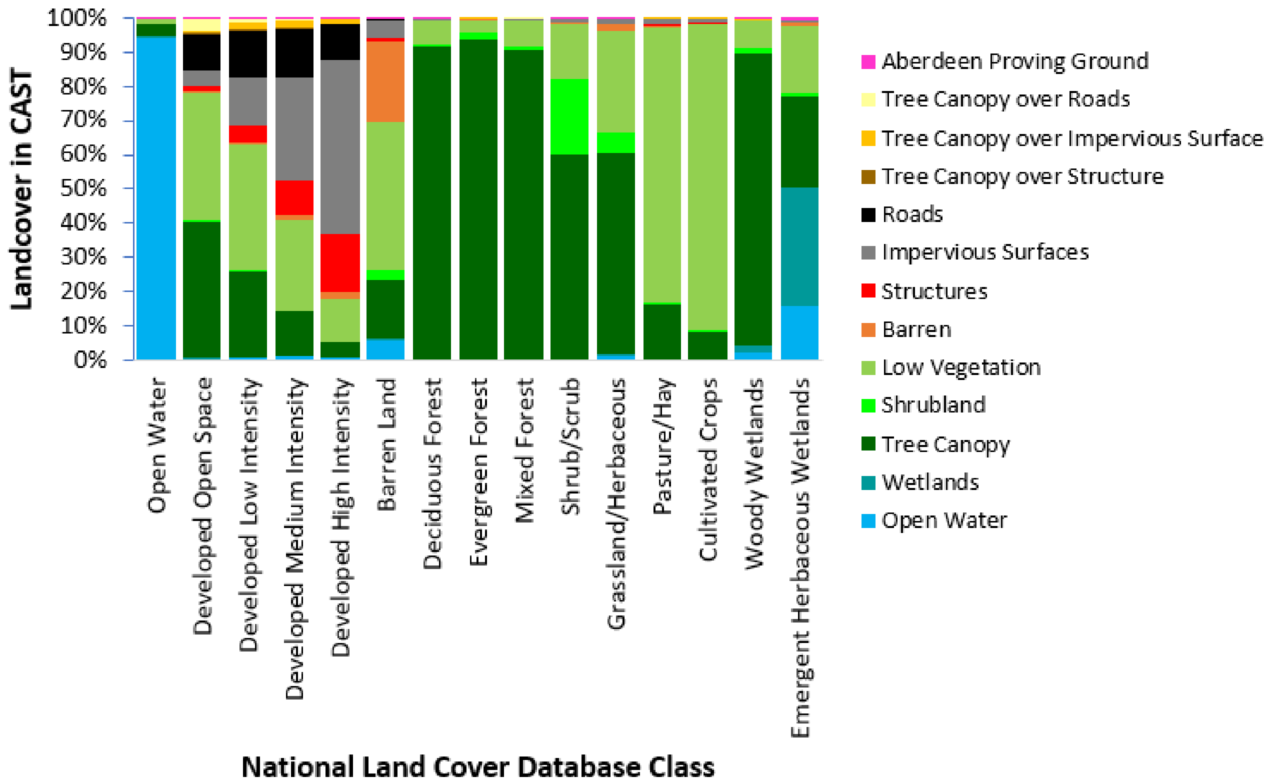

Figure A1.2. Relative contribution of CAST landcover classes to each NLCD land cover class in the Chesapeake Bay watershed.

In general, each BMP was assigned to a Chesapeake Bay land cover category (Table A1.1). For compatibility with Chesapeake Bay Program tools, acres of implementation of each BMP would be associated with increased acres of the corresponding land cover type.

Table A1.1. Assignment of each BMP to preserving or increasing acres of landcover in Chesapeake Bay Conservancy 1 m 2013/2014 land cover data.

BMP	CHESAPEAKE BAY 1 M LAND COVER CLASS
Agricultural Forest Buffer	Natural Tree Canopy
Agricultural Tree Planting	Natural Tree Canopy
Cover Crop	Low Vegetation
Forest Conservation	Natural Tree Canopy
Grass Buffer	Low Vegetation
Impervious Surface Reduction	Low Vegetation
Urban Forest Buffer	Tree Canopy Over Impervious Surfaces or Roads
Urban Forest Planting	Tree Canopy Over Impervious Surfaces or Roads
Urban Tree Planting	Tree Canopy Over Impervious Surfaces or Roads
Wetland Creation	Wetland
Wetland Restoration	Wetland

A2. Air Quality

Metric

Air pollutant removal of carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), large particulate matter (PM_{10}), small particulate matter ($PM_{2.5}$), sulfur dioxide (SO_2)

Approach

The following approach was used to spatially map air pollutant removal for counties throughout the watershed, and compare across BMPs as shown in Section 3.2.

1. For BMPs that involved trees we used iTree Canopy rural and urban removal multipliers and area of tree cover, we obtained and converted rural multiplier and urban multiplier from iTree Canopy Air Pollutant Removal methods to lb $acre^{-1}$ yr^{-1} (Table A2.1).

Table A2.1: Air pollutant removal multipliers adapted from iTree Canopy. Units are lb $acre^{-1}$ yr^{-1}

POLLUTANT	RURAL MULTIPLIER	URBAN MULTIPLIER
CO	0.893	1.13411
NO_2	4.86685	6.251
O_3	49.05249	48.25772
PM_{10}	16.52943	13.69862
$PM_{2.5}$	2.37538	2.46468
SO_2	3.09871	3.07192

1. For BMPs with low vegetation or grassland, we used urban and rural multipliers from Gopalakrishnan et al. (2018) and area of grassland or low vegetation (Table A2.2). Rural multiplier and urban multiplier from Gopalakrishnan et al. (2018) were converted to lb $acre^{-1}$ yr^{-1}.

Table A2.2. Air pollutant removal multipliers adapted from Gopalakrishnan et al. 2018. Units lb $acre^{-1}$ yr^{-1}

POLLUTANT	RURAL MULTIPLIER	URBAN MULTIPLIER
NO_2	2.2304475	3.211844
O_3	21.6799497	26.14084
PM2.5	0.2676537	0.356872
SO_2	1.2490506	1.427486

2. To quantify current air pollutant removal per county:
   a. Calculate acres of tree cover per county and multiply by the rural multipliers to estimate “natural” tree canopy removal potential.
   b. Calculate acres of tree cover over impervious, roads and structures and multiply by the urban removal multipliers to estimate urban tree canopy removal potential.
   c. Calculate total removal potential by summing the urban and rural estimates for each county.

4. To quantify potential pollutant removal for specific tree canopy BMPs:
    a. For urban BMPs (Urban Forest buffers, forest planting, tree planting) multiply acres of BMP by urban multipliers to estimate removal potential for implementing the BMP (Table A2.3).
    b. For agriculture BMPs (forest buffers, tree planting) multiply acres of BMP by rural multipliers to estimate removal potential for implementing the BMP (Table A2.3).
    c. For forest conservation, multiply acres of BMP by rural multipliers to estimate removal potentials (Table A2.3).
5. To quantify potential pollutant removal for low vegetation or grassland BMPs:
    a. For urban BMPs (Impervious surface reduction) multiply acres of BMP by urban multipliers to estimate removal potential for implementing the BMP (Table A2.3).
    b. For agriculture BMPs (Agricultural grass buffers) multiply acres of BMP by rural multipliers to estimate removal potential for implementing the BMP (Table A2.3).
6. BMPs not specifically linked to tree canopy cover or grass (i.e., wetland or cover crop) could not be explicitly quantified, so we assumed wetlands, which are primarily emergent herbaceous, and cover crops to be comparable to rural low vegetation based on the overlap between CAST land coverages and NLCD (see Appendix A1).

Table A2.3: BMPs and the corresponding air pollutant removal multiplier used to quantify lb/acre/yr of each air pollutant removed. Multipliers are based on iTree multipliers in Tables A2.1 and A2.2.

BMP	CO MULTIPLIER	O_3 MULTIPLIER	SO_2 MULTIPLIER	NO_2 MULTIPLIER	$PM_{2.5}$ MULTIPLIER	PM_{10} MULTIPLIER
AG FOREST BUFFER	0.893	49.05249	3.09871	4.86685	2.37538	16.52943
AG TREE PLANTING	0.893	49.05249	3.09871	4.86685	2.37538	16.52943
COVER CROPS	---	21.67995	1.249051	2.230448	0.267654	---
FOREST CONSERVATION	0.893	49.05249	3.09871	4.86685	2.37538	16.52943
GRASS BUFFER	---	21.67995	1.249051	2.230448	0.267654	---
IMPERVIOUS SURFACE REDUCTION	---	26.14084	1.427486	3.211844	0.356872	---
URBAN FOREST BUFFER	1.13411	48.25772	3.07192	6.251	2.46468	13.69862
URBAN FOREST PLANTING	1.13411	48.25772	3.07192	6.251	2.46468	13.69862
URBAN TREE PLANTING	1.13411	48.25772	3.07192	6.251	2.46468	13.69862
WETLAND CREATION	---	21.67995	1.249051	2.230448	0.267654	---
WETLAND RESTORATION	---	21.67995	1.249051	2.230448	0.267654	---

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A3. Bird Species for Wildlife Viewing

Metric

Bird species richness

Approach

The following approach was used to spatially map bird species richness for counties throughout the watershed, and compare across BMPs as shown in **Section 3.3**.

To quantify bird species richness for specific BMPS

Use USGS GAP bird species richness maps for US and identify the max bird species found in varying areas of land use type (from 1m 2013/2014 CAST LULC dataset). Then, use these results to build species area curves for each land use type. In theory number of species (S) will change with area (A) depending on constants c and z (Gotelli 1998) as

$$S = C*A^Z, \qquad (Eq.\ A3.1)$$

which on a log-log axis can be linearized as

$$\log(S)= z*\log(A) + \log(c), \qquad (Eq.\ A3.2)$$

where c (y-intercept) and z (slope) are constants are determined from model output. Tree plantings were assumed to have comparable results to tree canopy if implemented over large areas; plantings of a single or few trees would have much less impact on species richness. Cover crops, which are not explicitly mapped in the CAST land cover data, were assumed to be comparable to low vegetation (see **Appendix A1**).

To estimate mean species richness for a certain land use based on an area, plug the known area (in acres) into the equation (Table A3.1). Because species-area curves are non-linear, fewer bird species are added with each acre as the total number of contiguous acres becomes large. Additional bird richness per acre of BMP implementation can be calculated as the difference between estimated richness on existing contiguous acres of habitat and estimated richness on the total number of acres after BMP implementation (existing plus new).

Table A3.1: Species area curves for each land use category from the 2013/2014 1m dataset and the corresponding BMP. Area (A) is in acres.

LAND USE	SPECIES AREA EQUATION:	BMP ASSOCIATED WITH
NATURAL TREE CANOPY	S=68.97505379*A^0.0382277	Agricultural Forest Buffer; Agricultural Tree Planting; Forest Conservation
LOW VEGETATION	S=67.089448*A^0.04234895	Grass Buffer; Impervious Surface Reduction; Cover crop
WETLAND	S=84.59380187*A^0.0293969	Wetland Creation; Wetland Restoration
SHRUBLAND	S=62.57623*A^0.043156	---
STRUCTURES	S=64.336495*A^0.0626076	---
IMPERVIOUS SURFACES	S=63.974424*A^0.0667202	---

IMPERVIOUS ROADS	S=69.258172*A^0.0578431	---
TREE CANOPY OVER STRUCUTURE	S=74.044526*A^0.0550576	---
TREE CANOPY OVER IMPERVIOUS SURFACES	S=71.361518*A^0.0535650	Urban Forest Buffer; Urban Forest Planting
TREE CANOPY OVER IMPERVIOUS ROADS	S=73.325800*A^0.0502914	Urban Tree Planting
WATER	S=44.462915*A^0.0519981	---

Detailed steps in GIS

1. Create a Random Raster (extent and snap to USGS Bird Species Richness Raster); This will be used for the random subsampling of all cells later.
2. Create a New raster of Species Richness only on "Forest" habitat using RasterCalculator and SetNull to remove (i.e., set as empty or NA) any Non-forest cells. This will be used to calculate the max Richness in neighborhoods of varying sizes, but only on Forest habitat.
3. Create a New raster that flags "Forest" cells as 1, and non-Forest as 0, also using RasterCalculator and SetNull; this will be used to calculate the Area of Forest habitat (by summing the 1s) in neighborhoods of varying sizes.
4. Use Focal Statistics to calculate the MAX richness in Rectangle neighborhoods of varying sizes (1x1 cells to 30x30 cells) around each focal cell. This will indicate the dependent variable of species richness "S" in the species-area equation (Eq. A3.1).
5. Use Focal Statistics to calculate the sum total number of Forest cells in those rectangle neighborhoods. This will indicate the independent variable of area "A" in the species-area equation (Eq. A3.1).
6. Use the Random Raster (Step 1) to randomly sample 10% of the Forest Cells (using Raster Calculator and Set Null). Convert this Subset Raster to Points (makes next step faster).
7. Use Sample raster to export the subsampled raster data as a table for each Max Richness "S" and corresponding Area "A" for each neighborhood size. Area here is measured in terms of # of 30x30 meter cells which need to be converted to total acres.
8. The randomly sampled richness and area data are linearized by converting to a log-scale (Eq. A3.2) and analyzed using linear regression to estimate coefficients z (slope) and log(c) (intercept).
9. Repeat steps 2-9 for next land type.

To quantify current bird species richness per county

1. Calculate mean bird species richness in each county using zonal statistics tool in ArcGIS. Note that the USGS GAP bird species richness is based on 2011 NLCD land use land cover data and is at 30x30m resolution.

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USGS Gap: https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap

A4. Carbon Sequestration

Metric

Rate of carbon sequestration into soil

Approach

The following approach was used to spatially map carbon sequestration for counties throughout the watershed, and compare across BMPs as shown in **Section 3.4**.

1. Conducted literature search and used COMET planner to identify reported soil carbon sequestration values for different BMPs (Table A4.1). Where possible, we attempted to match literature descriptions to BMP descriptions (e.g., riparian forest, not just forest). Detailed literature information is in **Appendix A10** (Table A10.2). COMET values were used preferentially over literature values, if available.
2. Calculate the average of the report values for each different BMP, where multiple values available.
3. Converted literature values to US tons acre^{-1} yr^{-1}.
4. To estimate US tons yr^{-1} sequestered, multiply the acres of BMP implemented to the corresponding estimated soil carbon sequestration rate.
5. Baseline soil carbon sequestration per county was estimated by multiplying the acres of landcover in the CAST landcover dataset by the corresponding rate per acre for tree canopy over impervious roads, surfaces, or structures (same as urban forest buffers), tree canopy (same as agricultural forest buffer), wetland (same as wetland creation), or low vegetation (same as grassland).

Table A4.1. Literature search results for Soil Carbon Sequestration for specific BMPs. The soil carbon sequestration estimate is based on the mean of all literature in the references per BMP. Detailed values for each citation in Table A10.2.

BMP	SOIL CARBON SEQUESTRATION (US TONS ACRE^{-1} YR^{-1})	REFERENCE
AG FOREST BUFFER	0.18	COMET PLANNER
AG TREE PLANTING	0.16	COMET PLANNER
COVER CROP	0.13	COMET PLANNER
GRASS BUFFER	0.15	COMET PLANNER
AG FOREST BUFFER, AG TREE PLANTING	0.54	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
COVER CROP	0.13	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A.;

		Poeplau, Christopher, and Axel Don. "Carbon sequestration in agricultural soils via cultivation of cover crops–A meta-analysis." Agriculture, Ecosystems & Environment 200 (2015): 33-41.; Ruis, S.J., and H. Blanco-Canqui. 2017. Cover Crops Could Offset Crop Residue Removal Effects on Soil Carbon and Other Properties: A Review. Agronomy Journal 109(5): 1785.
FOREST CONSERVATION	0.54	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
GRASS BUFFER	0.40	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
IMPERVIOUS SURFACE REDUCTION	0.62	Qian, Y., Follett, R.F. and Kimble, J.M. (2010), Soil Organic Carbon Input from Urban Turfgrasses. Soil Sci. Soc. Am. J., 74: 366-371. https://doi.org/10.2136/sssaj2009.0078
URBAN FOREST BUFFERS, URBAN FOREST PLANTING, URBAN TREE PLANTING	0.06	Pouyat, Richard V., Ian D. Yesilonis, and Nancy E. Golubiewski. "A comparison of soil organic carbon stocks between residential turf grass and native soil." Urban Ecosystems 12.1 (2009): 45-62.
WETLAND CREATION, WETLAND RESTORATION	0.76	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x Craft C., Washburn C., Parker A. (2008) Latitudinal Trends in Organic Carbon Accumulation in Temperate Freshwater Peatlands. In: Vymazal J. (eds) Wastewater Treatment, Plant Dynamics and Management in Constructed and Natural Wetlands. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8235-1_3 Ensign, S. H., Noe, G. B., Hupp, C. R., and Skalak, K. J. (2015), Head-of-tide bottleneck of particulate material transport from watersheds to estuaries, Geophys. Res. Lett., 42, 10,671– 10,679, doi:10.1002/2015GL066830. Fennessy, M. S., et al. "Soil carbon sequestration in freshwater wetlands varies across a gradient of ecological condition and by ecoregion." Ecological Engineering 114 (2018): 129-136. Gary J. Whiting & Jeffrey P. Chanton (2001) Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration, Tellus B: Chemical and Physical Meteorology, 53:5, 521-528, DOI: 10.3402/tellusb.v53i5.16628 Loomis, M.J. and Craft, C.B. (2010), Carbon Sequestration and Nutrient (Nitrogen, Phosphorus) Accumulation in River-Dominated Tidal Marshes, Georgia, USA. Soil Sci. Soc. Am. J., 74: 1028-1036. https://doi.org/10.2136/sssaj2009.0171 Campbell, Elliott, Rachel Marks, and Christine Conn. "Spatial modeling of the biophysical and economic values of ecosystem services in Maryland, USA." Ecosystem Services 43 (2020): 101093.

A5. Flood Control

Metric

Maximum retained water volume (in^3/in^2 or $yd^3/acre$)

Approach

The following approach was used to spatially map maximum rainwater retention for counties throughout the watershed, and compare across BMPs as shown in Section 3.5. We calculated the maximum retained water volume using the Curve Number method (USDA/NRCS 1986). The capacity of landscape to retain water is one factor in determining rainwater runoff and streamflow (Section 3.11), along with other factors such as the intensity-duration-frequency (IDF) of precipitation, elevation, slope, and distance from stream.

To quantify maximum retained water volume per county:

1. Use USDA NRCS SSURGO database and create raster of soil hydrologic groups for each state in the watershed.
2. Mosaic the rasters together to form a single raster of all states and the corresponding soil groups.
3. Reclassify the soil hydrologic groups to numbers such that A, B, C, D are 1,2,3,4.
4. Use the combine tool to multiply the land cover land use raster (Chesapeake Bay 2013/2014 data) by the soil hydrologic group raster. This creates a new raster with every unique LULC x soil group value. Note: this raster is 10x10m because that is the resolution of the soil data raster.
5. Assign a curve number (CN) to each unique LULC x soil group based (Table A5.1, Tillman (2015)) and add this to the raster created in step 4.

Table A5.1. Curve Number values for different soil types and different land use land cover classes. Table adapted from Tillman 2015.

LULC	SOIL A/1	SOIL B/2	SOIL C/3	SOIL D/4	REFERENCE
WATER	100	100	100	100	Westenbroek and others (2010).
WETLAND	89	90	91	92	Westenbroek and others (2010).
TREE CANOPY	35.5	53	65	71.5	United States Department of Agriculture (2004), Table 9-2; Oak-aspen, fair; except A (Westenbroek and others, 2010); United States Department of Agriculture (2004), Table 9-2; Pinyon-juniper, fair; except A (Westenbroek and others, 2010).
SHRUB	49	68	79	84	United States Department of Agriculture (2004), Table 9-2; Desert shrub, good condition
LOW VEGETATION	64	71	81	89	United States Department of Agriculture (2004), Table 9-2; Herbaceous, fair; except A (Westenbroek and others, 2010).

BARREN	77	86	91	94	United States Department of Agriculture (2004), Table 9-1; Fallow, bare soil.
STRUCTURE	98	98	98	98	United States Department of Agriculture (2004), Table 9-5; Paved parking lots, roofs, driveways, etc.
IMPERVIOUS SURFACES	98	98	98	98	United States Department of Agriculture (2004), Table 9-5; Paved parking lots, roofs, driveways, etc.
ROADS	98	98	98	98	United States Department of Agriculture (2004), Table 9-5; Paved parking lots, roofs, driveways, etc.
TREE CANOPY OVER STRUCTURE	89	92	94	95	United States Department of Agriculture (2004), Table 9-5; Urban districts, commercial and business.
TREE CANOPY OVER IMPERVIOUS	77	86	91	94	United States Department of Agriculture (2004), Table 9-5; Developing urban areas
TREE CANOPY OVER ROADS	77	86	91	94	United States Department of Agriculture (2004), Table 9-5; Developing urban areas
ABERDEEN PROVING GROUND TREE CANOPY	35.5	53	65	71.5	United States Department of Agriculture (2004), Table 9-2; Oak-aspen, fair; except A (Westenbroek and others, 2010); United States Department of Agriculture (2004), Table 9-2; Pinyon-juniper, fair; except A (Westenbroek and others, 2010).

7. Open a shapefile that contains counties within the watershed. Use the tabulate area tool to calculate the area of each unique curve number in each county. Export these results to excel using the table to excel conversion tool.

8. In excel, calculate the percentage of each unique CN in each county by dividing the area of a unique CN by total area of the county. This will be used as the weighting factor.

9. Calculate a weighted mean for each county by summing all unique CN * Percent of area of that CN divided by the sum of all percent area CN for that county.

$$\frac{\sum_{county} CN * \ Percent\ area\ of\ CN}{\sum_{county} Percent\ area\ CN}$$

10. Calculate Maximum Retained Volume (in^3/in^2) per county using the following equation, where CN is the weighted mean CN for each county.

$$1.05 * \frac{1000}{CN} - 10$$

To quantify maximum retained water volume per BMP

1. Calculate the average CN for each land use in the watershed that corresponds to a BMP (Table A5.2). Cover crops, which are not explicitly mapped in CAST land cover data, were assumed to be low vegetation based on correspondence with NLCD land cover data (see [Appendix A1](#)). Urban forest buffers and forest plantings were assumed to be of sufficient area to have soil rainwater retention comparable to natural tree canopy, whereas urban tree plantings were assumed to be primarily over impervious surfaces.

Table A5.2. Mean Curve Number (CN) and Max retention volume associated with each land cover and corresponding BMP.

LULC	BMP	MEAN CN	MAX RETENTION VOLUME (IN^3/IN^2)
ABERDEEN PROVING GROUND TREE CANOPY	--	63.17	6.12
BARREN	--	87.00	1.57
IMPERVIOUS SURFACES	--	98.00	0.21
LOW VEGETATION	Cover Crops, Grass Buffers, Impervious surface reduction	76.27	3.27
ROADS	--	98.00	0.21
SHRUBLAND	--	70.00	4.50
STRUCTURE	--	98.00	0.21
TREE CANOPY	Ag Forest buffers, Ag Tree planting, Forest Conservation, Urban Forest Buffers, Urban forest planting	56.28	8.16
TREE CANOPY OVER IMPERVIOUS	Urban tree planting	87.75	1.47
TREE CANOPY OVER ROADS	--	87.33	1.52
TREE CANOPY OVER STRUCTURE	--	91.75	0.94
WATER	--	100.00	0.00
WETLAND	Wetland creation, restoration	90.50	1.10

2. Calculate maximum retained volume using the equation in step 10 above.
3. Multiply the maximum retained volume by the area of BMP implemented to get maximum retained volume in that area.

References

Staff, S. S. 2007. Gridded Soil Survey Geographic (gSSURGO) Database for the Conterminous United States. *in* N. R. C. S. United States Department of Agriculture, editor.

Tillman, F. D. 2015. Documentation of input datasets for the soil-water balance groundwater recharge model of the Upper Colorado River Basin. Report 2015-1160, Reston, VA.

USDA, and NRCS. 1986. Urban hydrology for small watersheds.

A6. Heat Risk or Extreme Temperature Reduction

Metric

Potential reduction in temperature due to presence of tree canopy

Approach

The following approach was used to spatially map temperature reduction for counties throughout the watershed, and compare across BMPs as shown in **Section 3.6**. Methods adapted from linear regression models to predict change in temperature in response to vegetative land cover (Murphy et al. 2011) and the Climate Change Vulnerability Assessment for Cambridge, MA report.

To calculate baseline cooling potential:

1. Get average air temperature (°C) for July 2014 for each land river segment (LRS). This data was provided by CAST. River segments with large acres of tree canopy (100000 acres or 156 square miles) had average July temperatures 1°F cooler or more than segments with substantially less tree canopy.
2. Convert temperature from °C to °F.
3. Get average tree canopy cover for each LRS (or county) using ArcGIS zonal statistics
4. Plot air temperature (°F) against tree canopy cover and calculate a simple linear regression:
    - $Y = -1.584 \times 10^{-5}$ * (acres of tree canopy) + 79.12
    - Multiple $R^2 = 0.4481$; adjusted $R^2 = 0.4453$
5. Use standard linear regression equation to estimate the cooling impact of tree canopy. Based on the best fit regression equation, each acre increase in tree canopy decreases air temperature by about -1.584×10^{-5} °F. River segments with large acres of tree canopy (>100000 acres) had average July temperatures 1°F cooler or more than segments with little tree canopy. To estimate cooling impact, multiply acres of tree canopy by the slope of the regression:
    - Cooling = -1.584×10^{-5} * (acres of tree canopy)

To calculate cooling potential for BMPs:

1. This method only applies to BMPs with tree canopy. Using multiple regression, we also investigated the relationships between temperature and low vegetation, impervious surface, wetland, and other CAST landcovers, but only tree canopy had a significant cooling effect.
2. Use the Cooling impact equation from step 4 above and enter the acres of a BMP that would produce tree canopy. This includes BMPs such as forest buffers and tree planting.
    - Example: 100 acres of forest buffer
      Cooling = -1.584×10^{-5} * (100 acres of forest buffer) = -0.001584 °F

References

City of Cambridge Massachusetts. 2015. Climate Change Vulnerability Assessment. Part 1. City of Cambridge, Massachusetts.

Murphy, D.J., M.H. Hall, C.A.S. Hall, G.M. Heisler, S.V. Stehman, and C. Anselmi-Molina. 2011. The relationship between land cover and the urban heat island in northeastern Puerto Rico. International Journal of Climatology 31:1222-1239.

A7. Open Space

Metric

Acres of open space per capita

Approach

The following approach was used to spatially map open space availability for counties throughout the watershed, and compare across BMPs as shown in **Section 3.7**. Open space was estimated as the accessibility of natural or semi-natural areas to people (Smith et al., 2014).

1. Get 2010 US census data (www.census.gov) and summarize to county level
2. Use tabulate area in ArcGIS to calculate land use acres per county
3. Summarize land covers to open space. Open space was assumed to include contiguous area of tree canopy, low vegetation, shrubland, or wetlands.
4. Calculate open space acres/capita by dividing total open space acres by population in each county.

As BMP acres are added, recalculate open space acres/capita:

Classify each BMP as adding contiguous acres of wetland, natural tree canopy, shrubland, or low vegetation in agricultural or urban areas. Urban tree plantings and impervious surface reduction are assumed to contribute to open areas if they are planted in a contiguous area of appreciable size (i.e., more than a single tree). Agricultural tree plantings, such as to reduce erosion, and cover crops are assumed here not to be open space accessible to people for recreational or aesthetic enjoyment.

1. Summarize land covers to open space. Open space includes the following:
   a. Wetland, tree canopy, shrubland, low vegetation (this is based on the 1m LULC)
2. Calculate open space acres/capita by dividing open space acres by population in each county.

Table A7.1. Land cover associated with each BMP.

BMP	CONVERTS TO LAND COVER (FOR PURPOSES OF CALCULATING OPEN SPACE)
GRASS BUFFERS, IMPERVIOUS SURFACE REDUCTION	Low vegetation
AG FOREST BUFFERS, FOREST CONSERVATION, URBAN FOREST BUFFERS, URBAN FOREST PLANTING, URBAN TREE PLANTING	Tree canopy
WETLAND CREATION WETLAND RESTORATION	Wetland

References

Smith, L.M., C.M. Wade, K.R. Straub, L.C. Harwell, J.L. Case, M. Harwell, J.K. Summers. 2014. Indicators and Methods for Evaluating Economic, Ecosystem, and Social Services Provisioning. US Environmental Protection Agency EPA/600/R-14/184.

A8. Pathogen Reduction

Metric

% FIB (Fecal Indicator Bacteria) Removed

Approach

The following approach was used to spatially map pathogen reduction for counties throughout the watershed, and compare across BMPs as shown in Section 3.8. We adapted methods used in Wainger (2015), Richkus et al. (2016) that were based on Potomac watershed modeling study by Vann et al. (2002). We estimated the pathogen reductions (as percent removal FIB) likely to be associated with the following BMPs: forest buffers, grass buffers, wetland restoration, impervious surface reduction, urban forest buffers and urban forest planting.

To quantify % Potential FIB removed for specific BMPs:

1. We calculated the area of each land use per county using tabulate area in ArcGIS. Then we summarized the 1m dataset land uses into the following categories for the purposes of calculating baseline fecal loads: pasture, forest, and urban (Table A8.1). We did not separate cropland from pasture because the 1m CAST land cover dataset only differentiates low vegetation.

Table A8.1. Description of how land use was recategorized to calculate baseline loads.

NEW CATEGORY	1M LULC NAME
PASTURE	Low vegetation
FOREST	Tree canopy
URBAN	Structure, impervious surfaces, impervious roads, tree canopy over structure, tree canopy over impervious surfaces, tree canopy over impervious roads

2. We identified FIB removal efficiencies from Wainger 2015 and Richkus et al. 2016 (Table A8.2). Removal efficiencies for different BMPs depend on the land use category they are applied on. We used the same efficiency for urban forest buffers and urban forest planting. We also used the efficiency for wetland restoration based on cropland for our summarized pasture category as we assume some of the land classified as low vegetation is cropland.

Table A8.2. List of FIB efficiencies adapted from Wainger et al. 2015 and Richkus et al. 2016.

BMP	FIB EFFICIENCY	LAND USE CATEGORY
FOREST BUFFER UNFENCED	50%	Pasture, Urban
FOREST BUFFER FENCED	52%	Pasture
GRASS BUFFER (FENCED OR UNFENCED)	71%	Pasture
IMPERVIOUS SURFACE REDUCTION	57%	Urban
WETLANDS	48%	Urban
WETLAND RESTORATION	35%	Cropland, but we applied to pasture.

3. Then we used the following equation to estimate % Potential FIB reduction:

   $$\% \text{ FIB reduction} = \frac{Credited\ BMP\ acres}{Total\ land\ use\ acres\ the\ BMP\ was\ implemented\ on} * \%\ FIB\ efficiency$$

   Example: 100 acres of forest buffer were implemented on pasture (i.e., low vegetation) in a county with 1000 acres of pasture (low vegetation):

   % FIB reduction = 100/1000 * .5 = 0.05

To quantify an estimate of current pathogen loading for each county:

1. We used the modeled loadings from the Potomac River basin to estimate edge of stream delivery of fecal coliform (cfu/yr/acre) for pasture and urban land uses in each county (Table A8.3).

Table A8.3. Edge of stream delivery of fecal coliform for pasture and urban land uses adapted from Wainger et al. 2015.

LAND USE	EDGE OF STREAM DELIVERY PER ACRE (CFU/AC/YR)
PASTURE	3.88E+11
URBAN	1.82E+10

2. We multiplied the edge of stream delivery per acre for pasture and urban land cover for each county by the total acres of land cover. Then we calculated the total edge of stream delivery per county by summing the edge of stream delivery for pasture and urban in each county.

References

Richkus, J., L. A. Wainger, and M. C. Barber. 2016. Pathogen reduction co-benefits of nutrient best management practices. PeerJ **4**:e2713-e2713.

Vann, D. T., R. Mandel, J. M. Miller, E. Hagen, A. Buda, and D. Cordalis. 2002. The District of Columbia Source Water Assessment. Pages 6.1–6.40. Interstate Commission on the Potomac River Basin. Retrieved from http://www.potomacriver.org/publicationspdf/DC_SWA_redacted.pdf

Wainger, L., J. Richkus, M. Barber. 2015. Additional Beneficial Outcomes Of Implementing The Chesapeake Bay TMDL: Quantification And Description Of Ecosystem Services Not Monetized. U.S. Environmental Protection Agency, Washington, DC.

A9. Pollination

Metric

Index of pollinator supply based on habitat suitability

Approach

The following approach was used to spatially map pollinator supply for counties throughout the watershed, and compare across BMPs as shown in **Section 3.9**. Use InVEST Crop Pollination (Pollinator Abundance) spatial model (Sharp et al., 2020). This model creates an index of suitability for bees nesting on each cell (0-1; pollinator abundance index) and bees visiting each cell on a landscape (0-1; pollinator supply index). Higher scores indicate sources of greater relative bee abundance. The model requires a land use land cover map, land cover attributes, guilds or species of pollinators, and their flight ranges.

To run the model, we used the following data:

1. We used the Chesapeake Conservancy 1m dataset for the land cover map.
2. We identified four species generally present throughout the Chesapeake Bay watershed to model abundance for: Bumblebees, Bicolor sweat bee, blue sweat bee and orchard bee (Table A9.1). For each species we used literature to determine type of nesting (cavity or ground; 1 indicating suitable nesting), foraging activity in spring and summer (range 0-1), alpha (foraging distance in m), and relative abundance to each other in the watershed.

Table A9.1. Bee species characteristic values used in InVEST model.

SPECIES	CAVITY NESTING	GROUND NESTING	FORAGING ACTIVITY IN SPRING	FORAGING ACTIVITY IN SUMMER	ALPHA	REL. ABUNDANCE
BICOLORED STRIPED SWEAT BEE	0	1	0.8	0.8	500	0.5
AMERICAN BUMBLEBEE	0	1	0.8	1	3000	1
BLUE SWEAT BEE	1	0	0.7	0.7	750	0.5
BLUE ORCHARD BEE	1	0	1	0.5	500	0.7

3. We used expert opinion from an East Mount Zion, Pennsylvania case study (Sharpe et al., 2022) to determine nesting availability and floral resource availability for different land use land cover categories (Table A9.2).

Table A9.2. Land use nesting and floral resource characteristics used in the InVEST model.

LULC CATEGORY	NESTING CAVITY AVAILABILITY INDEX	NESTING GROUND AVAILABILITY INDEX	FLORAL RESOURCES SPRING INDEX	FLORAL RESOURCES SUMMER INDEX
OPEN WATER	0	0	0	0.3
EMERGENT WETLANDS	0.1	0	0.4	0.8
TREE CANOPY	0.8	0.7	0.5	0.35
SHRUBLAND	0.7	0.7	0.6	0.6
LOW VEGETATION	0.2	0.7	0.6	0.8
BARREN	0	0.3	0	0
STRUCTURES	0.4	0.3	0.2	0.2
IMPERVIOUS SURFACES	0.4	0.3	0.2	0.2
IMPERVIOUS ROADS	0.4	0.3	0.2	0.2
TREE CANOPY OVER STRUCTURE	0.6	0.4	0.3	0.3
TREE CANOPY OVER IMP SURFACE	0.6	0.4	0.3	0.3
TREE CANOPY OVER IMP ROADS	0.4	0.3	0.2	0.2
ABERDEEN PROVING GROUND	0	0	0	0

4. We uploaded this data to the InVEST model and it produced several rasters including pollinator abundance for each species during each season (depending on what seasons we input to the model) and pollinator supply for each species during each season. The pollinator abundance raster provides per-pixel abundance of each pollinator during each season, which was used to calculate a mean value per LULC category (Table A9.3). The pollinator supply raster provides the per pixel index of each pollinator that could be on a pixel given land cover attributes including habitat suitability and floral resources that a pollinator could reach from that pixel.

Table A9.3. Pollinator abundance index for each species for each land use category.

LULC CATEGORY	BUMBLEBEE	BICOLOR SWEAT BEE	BLUE SWEAT BEE	ORCHARD BEE
WATER	0.009	0.003	0.002	0.002
EMERGENT WETLAND	0.024	0.008	0.008	0.008
TREE CANOPY	0.020	0.009	0.009	0.008
SHRUBLAND	0.033	0.015	0.015	0.014
LOW VEG	0.044	0.020	0.015	0.013
BARREN	0.000	0.000	0.000	0.000
STRUCTURE	0.010	0.005	0.004	0.003
IMP SURFACES	0.010	0.005	0.004	0.003
IMP ROADS	0.011	0.005	0.004	0.004
TC OVER STRUCTURE	0.016	0.007	0.006	0.006
TC OVER IMP SURF	0.015	0.007	0.006	0.006
TC OVER IMP ROADS	0.011	0.005	0.005	0.004

5. Then we assigned pollinator abundances for each species to each BMP based on the most similar land use (**Table A9.4**).

Table A9.4: Pollinator abundance index for each BMP based on Table A9.3.

BMP NAME	BUMBLEBEE	BICOLOR SWEAT BEE	BLUE SWEAT BEE	ORCHARD BEE
AG FOREST BUFFERS & TREE PLANTING	0.020	0.009	0.009	0.008
COVER COVER	0.044	0.020	0.015	0.013
FOREST CONSERVATION	0.020	0.009	0.009	0.008
GRASS BUFFERS	0.044	0.020	0.015	0.013
IMPERVIOUS SURFACE REDUCTION	0.044	0.020	0.015	0.013
URBAN FOREST BUFFERS/PLANTING	0.020	0.009	0.009	0.008
URBAN TREE PLANTING	0.015	0.007	0.006	0.006
WETLAND CREATION/RESTORATION	0.024	0.008	0.008	0.008

References

Sharp, R., J. Douglass, S. Wolny, K. Arkema, J. Bernhardt, W. Bierbower, N. Chaumont, D. Denu, D. Fisher, K. Glowinski, R. Griffin, G. Guannel, A. Guerry, J. Johnson, P. Hamel, C. Kennedy, C. K. Kim, M. Lacayo, E. Lonsdorf, L. Mandle, L. Rogers, J. Silver, J. Toft, G. Verutes, A. L. Vogl, S. Wood, and K. Wyatt. 2020. InVEST 3.8.9 User's Guide.

Sharpe et al. 2022. Use of Ecosystem Goods and Services and Community Engagement in the Restoration and Revitalization of Contaminated Sites: East Mount Zion Landfill Revitalization Project. EPA Report (In prep.)

A10. Soil Quality

Metric

Soil carbon stock

Approach

The following approach was used to spatially map carbon stock in soil for counties throughout the watershed, and compare across BMPs as shown in **Section 3.10**.

1. Conducted literature search for reported soil carbon stock values for different BMPs and land uses (Table A10.1).
2. Calculate the average of the reported values for each different BMP and/or land use, where multiple values available.
3. Converted literature values to US tons acre^{-1} (Table A10.1)
4. To estimate lb acre^{-1} stock, multiply the acres of BMP implemented to the corresponding estimated soil carbon stock.
5. Baseline soil carbon stock per county was estimated by multiplying the acres of landcover in the CAST landcover dataset by the corresponding soil carbon stock per acre for tree canopy over impervious roads, surfaces, or structures (same as urban forest buffers), tree canopy (same as agricultural forest buffer), wetland (same as wetland creation), or low vegetation (same as grassland).

Table A10.1. Literature search results for BMPs and Soil Carbon stock estimates. Soil carbon stock is based on the average of listed references for each BMP. Detailed values for each citation in Table A10.2.

BMP	SOIL CARBON STOCK (US TONS PER ACRE)	REFERENCES
AG FOREST BUFFER; AG TREE PLANTING; FOREST CONSERVATION	14.47	Dybala, Kristen E., et al. "Carbon sequestration in riparian forests: A global synthesis and meta-analysis." Global change biology 25.1 (2019): 57-67; Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105; Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140; Udawatta, Ranjith P., and Shibu Jose. "Carbon sequestration potential of agroforestry practices in temperate North America." Carbon sequestration potential of agroforestry systems. Springer, Dordrecht, 2011. 17-42

COVER CROP	1.32	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A; Tautges, Nicole E., et al. "Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils." Global change biology 25.11 (2019): 3753-3766
GRASS BUFFER	12.75	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105; Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140; Salehin, S..M.-U.-; Ghimire, R.; Angadi, S.V.; Idowu, O.J. Grass Buffer Strips Improve Soil Health and Mitigate Greenhouse Gas Emissions in Center-Pivot Irrigated Cropping Systems. Sustainability 2020, 12, 6014. https://doi.org/10.3390/su12156014
IMPERVIOUS SURFACE REDUCTION	64.30	Pouyat, Richard V., Ian D. Yesilonis, and David J. Nowak. "Carbon storage by urban soils in the United States." Journal of environmental quality 35.4 (2006): 1566-1575
URBAN FOREST BUFFERS; URBAN FOREST PLANTING; URBAN TREE PLANTING	47.91	Pouyat, Richard V., Ian D. Yesilonis, and David J. Nowak. "Carbon storage by urban soils in the United States." Journal of environmental quality 35.4 (2006): 1566-1575; Pouyat, Richard V., Ian D. Yesilonis, and Nancy E. Golubiewski. "A comparison of soil organic carbon stocks between residential turf grass and native soil." Urban Ecosystems 12.1 (2009): 45-62
WETLAND CREATION AND RESTORATION	65.83	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x; Krauss, K. W., Noe, G. B., Duberstein, J. A., Conner, W. H., Stagg, C. L., Cormier, N., et al. (2018). The role of the upper tidal estuary in wetland blue carbon storage and flux. Global Biogeochemical Cycles, 32, 817– 839. https://doi.org/10.1029/2018GB005897

Table A10.2. Detailed information from literature search for soil carbon stock ([Appendix A10]) and sequestration ([Appendix A4]) for different BMPs and land use land cover.

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
CONSTRUCTED MARSH	North Carolina	42	g C m-2 yr-1	---	---		Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., Zheng, L. and Sacco, J. (2003), THE PACE OF ECOSYSTEM DEVELOPMENT OF CONSTRUCTED SPARTINA ALTERNIFLORA MARSHES. Ecological Applications, 13: 1417-1432. https://doi.org/10.1890/02-5086
COVER CROPS	Global	0.32	mg C ha-1 yr-1	---	---	25 studies	Poeplau, Christopher, and Axel Don. "Carbon sequestration in agricultural soils via cultivation of cover crops–A meta-analysis." Agriculture, Ecosystems & Environment 200 (2015): 33-41.
COVER CROPS	Global	0.48	mg C ha-1 yr-1	---	---	based on 26 studies	Ruis, S.J., and H. Blanco-Canqui. 2017. Cover Crops Could Offset Crop Residue Removal Effects on Soil Carbon and Other Properties: A Review. Agronomy Journal 109(5): 1785.
COVER CROPS	USA	0.15	mg C ha-1 yr-1	0.2	---	---	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A.
COVER CROPS	USA	0.22	mg C ha-1 yr-1	0.2	---	---	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A.
COVER CROPS	USA	3	Mg ha-1	0.2	20	Based on 20 years.	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A.
COVER CROPS	USA	4.4	Mg ha-1	0.2	20	Based on 20 years.	Chambers, Adam, Rattan Lal, and Keith Paustian. "Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative." Journal of Soil and Water Conservation 71.3 (2016): 68A-74A.

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
COVER CROPS	Ca, USA	1.44	Mg ha-1	0.3	19	tomato-maize system	Tautges, Nicole E., et al. "Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils." Global change biology 25.11 (2019): 3753-3766.
FOREST REMNANT	Baltimore, MD	5.44	kg m-2	1	100	mention preserved for ~100yrs	Raciti, S.M., Groffman, P.M., Jenkins, J.C. et al. Accumulation of Carbon and Nitrogen in Residential Soils with Different Land-Use Histories. Ecosystems 14, 287–297 (2011). https://doi.org/10.1007/s10021-010-9409-3
FOREST REMNANT	Baltimore, MD	0.0544	kg C m-2 yr-1	1	100	divided above by #years to get annual estimate	Raciti, S.M., Groffman, P.M., Jenkins, J.C. et al. Accumulation of Carbon and Nitrogen in Residential Soils with Different Land-Use Histories. Ecosystems 14, 287–297 (2011). https://doi.org/10.1007/s10021-010-9409-3
FRESHWATER WETLAND	Virginia	105	g C m-2 yr-1	.3-.5	1964-2008	dismal swamp	Craft C., Washburn C., Parker A. (2008) Latitudinal Trends in Organic Carbon Accumulation in Temperate Freshwater Peatlands. In: Vymazal J. (eds) Wastewater Treatment, Plant Dynamics and Management in Constructed and Natural Wetlands. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8235-1_3
FRESHWATER WETLAND	Virginia	97	g C m-2 yr-1	---	---	arum arrow marsh	Gary J. Whiting & Jeffrey P. Chanton (2001) Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration, Tellus B: Chemical and Physical Meteorology, 53:5, 521-528, DOI: 10.3402/tellusb.v53i5.16628
FRESHWATER WETLAND	Ohio, PA	75	g C m-2 yr-1	.4-.5	1964-2010/11	mean of ohio and PA sites	Fennessy, M. S., et al. "Soil carbon sequestration in freshwater wetlands varies across a gradient of ecological condition and by ecoregion." Ecological Engineering 114 (2018): 129-136.
FRESHWATER WETLAND	Maryland	105	g C m-2 yr-1	---	---	fw forested, range 105-182	Ensign, S. H., Noe, G. B., Hupp, C. R., and Skalak, K. J. (2015), Head-of-tide bottleneck of particulate material transport from watersheds to estuaries, Geophys. Res. Lett., 42, 10,671– 10,679, doi:10.1002/2015GL066830.

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
FRESHWATER WETLAND	Georgia	124	g C m-2 yr-1	---	---	fw tidal	Loomis, M.J. and Craft, C.B. (2010), Carbon Sequestration and Nutrient (Nitrogen, Phosphorus) Accumulation in River-Dominated Tidal Marshes, Georgia, USA. Soil Sci. Soc. Am. J., 74: 1028-1036. https://doi.org/10.2136/sssaj2009.0171
FRESHWATER WETLAND	Waccamaw River	386.1	Mg ha-1	.5m		fw tidal, 0-.5m	Krauss, K. W., Noe, G. B., Duberstein, J. A., Conner, W. H., Stagg, C. L., Cormier, N., et al. (2018). The role of the upper tidal estuary in wetland blue carbon storage and flux. Global Biogeochemical Cycles, 32, 817– 839. https://doi.org/10.1029/2018GB005897
FRESHWATER WETLAND	Savannah River	146.8	Mg ha-1	.5m	---	fw tidal, 0-.5m	Krauss, K. W., Noe, G. B., Duberstein, J. A., Conner, W. H., Stagg, C. L., Cormier, N., et al. (2018). The role of the upper tidal estuary in wetland blue carbon storage and flux. Global Biogeochemical Cycles, 32, 817– 839. https://doi.org/10.1029/2018GB005897
FRESHWATER WETLAND	Ohio	4.18	kg m-2	0.35	1964-2012	mean of SOC concentration isolated wetlands from study	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x
FRESHWATER WETLAND	Ohio	1.5	kg m-2	0.35	1964-2012	mean of riverine SOC concentration wetlands from study	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x
FRESHWATER WETLAND	Ohio	41.8	Mg ha-1	0.35	1964-2012	mean of SOC concentration isolated wetlands from study, 0-.35m	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
FRESHWATER WETLAND	Ohio	15	Mg ha-1	0.35	1964-2012	mean of riverine SOC concentration wetlands from study, 0-.35m	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x
FRESHWATER WETLAND	Ohio	317	g C m-2 yr-1	0.35	1964-2012	mean of C sequestration rate isolated wetlands from study	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x
FRESHWATER WETLAND	Ohio	140	g C m-2 yr-1	0.35	1964-2012	mean of riverine C sequestration rate wetlands from study	Bernal, B. and Mitsch, W.J. (2012), Comparing carbon sequestration in temperate freshwater wetland communities. Glob Change Biol, 18: 1636-1647. https://doi.org/10.1111/j.1365-2486.2011.02619.x
GRASS BUFFER	Iowa	1.8	Mg ha-1	---	6	switchgrass, 6 yrs	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
GRASS BUFFER	Iowa	1.8	Mg ha-1		6	cool season grass, 6 yrs	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
GRASS BUFFER	Iowa	47.2	Mg ha-1	---	7 to 17	warm season grass, 7-17 yrs	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.
GRASS BUFFER	Iowa	55.3	Mg ha-1	---	7 to 17	cool season grass, 7-17 yrs	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
GRASS BUFFER	Iowa	56.2	Mg ha-1	---	16 to 26	warm season grass, 16-26 yrs	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.
GRASS BUFFER	Iowa	57.8	Mg ha-1	---	16 to 26	cool season grass, 16-26 yrs	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.
GRASS BUFFER	Missouri	1.7	% mass	---	---	--	Paudel, B. R., Udawatta, R. P., & Anderson, S. H. (2011). Agroforestry and grass buffer effects on soil quality parameters for grazed pasture and row-crop systems. Applied Soil Ecology, 48(2), 125-132. https://doi.org/10.1016/j.apsoil.2011.04.004
GRASS BUFFER	New Mexico	13.83	Mg ha-1	---	---	measured in spring, summer, fall and presented as mean +/` SE	Salehin, S..M.-U.-; Ghimire, R.; Angadi, S.V.; Idowu, O.J. Grass Buffer Strips Improve Soil Health and Mitigate Greenhouse Gas Emissions in Center-Pivot Irrigated Cropping Systems. Sustainability 2020, 12, 6014. https://doi.org/10.3390/su12156014
GRASS BUFFER	New Mexico	11.87	Mg ha-1	---	---	---	Pouyat, R.V., Yesilonis, I.D. and Nowak, D.J. (2006), Carbon Storage by Urban Soils in the United States. J. Environ. Qual., 35: 1566-1575. https://doi.org/10.2134/jeq2005.0215
GRASS BUFFER	New Mexico	11.14	Mg ha-1	---	---	---	Pouyat, R.V., Yesilonis, I.D. and Nowak, D.J. (2006), Carbon Storage by Urban Soils in the United States. J. Environ. Qual., 35: 1566-1575. https://doi.org/10.2134/jeq2005.0215
GRASS BUFFER	Iowa	0.9	Mg C ha-1 yr-1		6	switchgrass, 6 yrs	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
PLANTED WETLAND	Midwest, USA	190	g C m-2 yr-1		10	measured after 10yrs	Anderson CJ, Mitsch WJ (2006) Sediment, carbon, and nutrientaccumulation at two 10-year-old created riverine marshes.Wetlands 26:779–792

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
PLANTED WETLAND	Midwest, USA	242	g C m-2 yr-1		15	measured after 15 yrs	Bernal, Blanca, and William J. Mitsch. "Carbon sequestration in two created riverine wetlands in the Midwestern United States." Journal of Environmental Quality 42.4 (2013): 1236-1244.
RESIDENTIAL LAWN		14.4	kg m-2	1m	---	older residential lawns at 1m	Pouyat, R.V., Yesilonis, I.D. and Nowak, D.J. (2006), Carbon Storage by Urban Soils in the United States. J. Environ. Qual., 35: 1566-1575. https://doi.org/10.2134/jeq2005.0215
RIPARIAN BUFFER	USA, Mostly Iowa	3.6	Mg ha-1	---	---	mean from all studies in paper. Unclear exactly what studies were used to calculate this.	Udawatta, R. P. and S. Jose. 2012. Agroforestry strategies to sequester carbon in temperate North America. Agroforestry systems, 86, 225-242. doi: 10.1007/s10457-012-9561-1
RIPARIAN BUFFER	Iowa	2.4	Mg ha-1	---	6	poplar dominated and 6 yr old	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.
RIPARIAN BUFFER	Iowa	50.2	Mg ha-1	---	7 to 17	7-17 yr old	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.
RIPARIAN BUFFER	Iowa	70.8	Mg ha-1	---	16 to 26	16-26 yr old	Kim, Dong-Gill, et al. "Methane flux in cropland and adjacent riparian buffers with different vegetation covers." Journal of environmental quality 39.1 (2010): 97-105.
RIPARIAN BUFFER	Global	35	Mg ha-1	---	---	this is the median at maturity	Dybala, KE, Matzek, V, Gardali, T, Seavy, NE. Carbon sequestration in riparian forests: A global synthesis and meta-analysis. Glob Change Biol. 2019; 25: 57– 67. https://doi.org/10.1111/gcb.14475
RIPARIAN BUFFER	Iowa	1.2	Mg ha-1 yr-1	---	---	poplar dominated	Marquez, Carmen Omaira, et al. "Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA." Agroforestry Systems 44.2 (1998): 133-140.

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
TURF GRASS		1.39	Mg ha-1 yr-1	---	4	fine fescue	Qian, Y., Follett, R.F. and Kimble, J.M. (2010), Soil Organic Carbon Input from Urban Turfgrasses. Soil Sci. Soc. Am. J., 74: 366-371. https://doi.org/10.2136/sssaj2009.0075
TURF GRASS		3.35	Mg ha-1 yr-1	---	4	fine fescue irrigated	Qian, Y., Follett, R.F. and Kimble, J.M. (2010), Soil Organic Carbon Input from Urban Turfgrasses. Soil Sci. Soc. Am. J., 74: 366-371. https://doi.org/10.2136/sssaj2009.0076
TURF GRASS		2.05	Mg ha-1 yr-1	---	4	kentucky bluegrass	Qian, Y., Follett, R.F. and Kimble, J.M. (2010), Soil Organic Carbon Input from Urban Turfgrasses. Soil Sci. Soc. Am. J., 74: 366-371. https://doi.org/10.2136/sssaj2009.0077
TURF GRASS		2.28	Mg ha-1 yr-1		4	creeping bentgrass	Qian, Y., Follett, R.F. and Kimble, J.M. (2010), Soil Organic Carbon Input from Urban Turfgrasses. Soil Sci. Soc. Am. J., 74: 366-371. https://doi.org/10.2136/sssaj2009.0078
TURF GRASS		0.082	kg C m-2 yr-1	--	---	residential lawn	Raciti, S.M., Groffman, P.M., Jenkins, J.C. *et al.* Accumulation of Carbon and Nitrogen in Residential Soils with Different Land-Use Histories. *Ecosystems* **14,** 287–297 (2011). https://doi.org/10.1007/s10021-010-9409-3
TURF GRASS		0.1	kg C m-2 yr-1	---	---	golf course	Qian, Y.L., and R.F. Follett. 2002. Assessing soil carbon sequestration in turfgrasssystems using long-term soil testing data. Agron. J. 94:930–935
TURF GRASS	USA	2.8	Mg ha-1 yr-1	0.15	---	mean for several us cities	Selhorst, A., Lal, R. Net Carbon Sequestration Potential and Emissions in Home Lawn Turfgrasses of the United States. Environmental Management 51, 198–208 (2013). https://doi.org/10.1007/s00267-012-9967-6
URBAN FOREST REMNANT	Baltimore, MD	12.1	kg m-2	1	~80	soil organic carbon density	Pouyat, R.V., Yesilonis, I.D. & Golubiewski, N.E. A comparison of soil organic carbon stocks between residential turf grass and native soil. Urban Ecosyst 12, 45–62 (2009). https://doi.org/10.1007/s11252-008-0059-6
URBAN FOREST REMNANT	Baltimore, MD	10.5	kg m-2	1	~80	soil organic carbon density	Pouyat, R.V., Yesilonis, I.D. & Golubiewski, N.E. A comparison of soil organic carbon stocks between residential turf grass and native soil. Urban Ecosyst 12, 45–62 (2009). https://doi.org/10.1007/s11252-008-0059-6

LAND USE	Location	SOIL CARBON	UNITS	SOIL DEPTH	TIMEFRAME (YEARS)	ADDITIONAL INFO	SOURCE
URBAN FOREST REMNANT	Baltimore, MD	0.15125	kg C m-2 yr-1	1	~80	divided total carbon density by # years	Pouyat, R.V., Yesilonis, I.D. & Golubiewski, N.E. A comparison of soil organic carbon stocks between residential turf grass and native soil. Urban Ecosyst 12, 45–62 (2009). https://doi.org/10.1007/s11252-008-0059-6
URBAN FOREST REMNANT	Baltimore, MD	0.13125	kg C m-2 yr-1	1	~80		Pouyat, R.V., Yesilonis, I.D. & Golubiewski, N.E. A comparison of soil organic carbon stocks between residential turf grass and native soil. Urban Ecosyst 12, 45–62 (2009). https://doi.org/10.1007/s11252-008-0059-6
URBAN FOREST REMNANT	Mean Of Select Us Cities	9.6	kg m-2	---	---	: Atlanta, Baltimore. Boston, Chicago, Oakland. and Syracuse	Pouyat RV, Yesilonis I, Russell-Anelli J, Neerchal NK (2007) Soilchemical and physical properties that differentiate urban land-useand cover. Soil Sci Soc Am J 71(3):1010–1019
FRESHWATER WETLAND	Maryland	391.72	g C m-2 yr-1	---	---	based on values from 30 sites	Campbell, Elliott, Rachel Marks, and Christine Conn. "Spatial modeling of the biophysical and economic values of ecosystem services in Maryland, USA." Ecosystem Services 43 (2020): 101093.

A11. Water Quantity

Metric

Surface water flow

Approach

The following approach was used to spatially map water quantity for counties throughout the watershed, and compare across BMPs as shown in **Section 3.11**. The capacity of landscape to retain water (**Section 3.5**) is one factor in determining rainwater runoff and streamflow, along with other factors such as the intensity-duration-frequency (IDF) of precipitation, elevation, slope, and distance from stream.

To quantify current water quantity per county:

1. Obtain annual surface water flow for each land use generated from the CAST model (https://cast.chesapeakebay.net/Documentation/ModelDocumentation) at the resolution of land river segments
2. Aggregate data at the land river segment scale to county by taking the average of annual surface water flow for all land river segments in the county

To quantify water quantity for specific BMPs:

1. Obtain annual surface water flow for each land use generated from the CAST model at the resolution of land river segments
2. Assign CAST land use categories to BMPs based on whether the BMP would become a certain land use (e.g., Ag forest buffers could become true forest) (Table A11.1).
3. Calculate the average annual surface water flow for each BMP based on the CAST land use categories (Table A11.1).

Table A11.1. Mean annual flow (in/yr) for BMPs and corresponding CAST land use categories.

BMP NAME	CAST MODELED LANDUSE CATEGORIES	MEAN ANNUAL FLOW (IN/YEAR)
AG FOREST BUFFERS	CSS Forest, True Forest	13.75
AG GRASS BUFFERS	Agricultural Open Space	15.09
COVER CROP	Leguminous Hay, Other Hay, Pasture, Double Cropped Land, Full Season Soybeans, Grain with Manure, Grain without Manure, Other Agronomic Crops, Silage with Manure, Silage without Manure, Small Grains and Grains, Specialty Crop High, Specialty Crop Low	15.62
FOREST CONSERVATION	True Forest	13.70
IMPERVIOUS SURFACE REDUCTION	CSS Turf Grass, MS4 Turf Grass, Non-regulated Turf Grass	19.91
URBAN FOREST BUFFERS AND PLANTING	CSS Forest, True Forest	13.75

URBAN TREE PLANTING	MS4 Tree Canopy over Impervious, MS4 Tree Canopy over Turf Grass, Non-regulated Tree Canopy over Impervious, Non-regulated Tree Canopy over Turf Grass, CSS Tree Canopy over Impervious, CSS Tree Canopy over Turf Grass	26.17
WETLAND CREATION/ RESTORATION	Non-tidal Floodplain wetland, Headwater or Isolated wetland	13.70

4. To map baseline surface water flow based on the Chesapeake Bay Conservancy 2013/2014 1 meter land use land cover data, CAST model detailed land use classes were assigned to LULC classes in the 1 meter data set (Table A11.2).

Table A11.2. Mean annual flow (in/yr) for BMPs and corresponding CAST land use categories.

LAND USE LAND COVER CLASS (2013/2014 1M DATASET)	CAST MODELED LANDUSE CATEGORIES	MEAN ANNUAL FLOW (IN/YEAR)
EMERGENT WETLAND	Non-tidal floodplain wetland, headwater or isolated wetland	13.70
TREE CANOPY	True forest, CSS forest, harvested forest	14.64
SHRUBLAND	Mixed open, CSS mixed open	14.30
LOW VEG	Ag Open Space, Non-Regulated Turf Grass, MS4 Turf Grass, CSS Turf Grass, Leguminous Hay, Other Hay, Pasture, Double Cropped Land, Full Season Soybeans, Grain with Manure, Grain without Manure, Other Agronomic Crops, Silage with Manure, Silage without Manure, Small Grains and Grains, Specialty Crop High, Specialty Crop Low, Non-Permitted Feeding Space, Permitted Feeding Space	18.04
STRUCTURE	MS4 buildings and other, CSS buildings and other, non-regulated building and other	32.42
IMP SURFACES	CSS construction, regulated construction	20.81
IMP ROADS	MS4 roads, non-regulated roads, CSS roads	32.42
TC OVER IMP SURF	MS4 tree canopy over impervious, non-regulated tree canopy over impervious, CSS tree canopy over impervious	32.42

References

Chesapeake Bay Program. 2020. Chesapeake Assessment and Scenario Tool (CAST) Version 2019. https://cast.chesapeakebay.net/Documentation/ModelDocumentation

A12. Additional Ecosystem Services Not Quantified

A12.1. Clean Water

Clean water with respect to nutrients was an important FEGS identified in our scoping. We did not focus efforts to quantify this FEGS because the CAST model already quantifies how BMPs impact nutrient delivery. Additional work could be done to quantify the impact of BMPs on nitrates in groundwater.

A12.2. Water Clarity

We attempted to quantify water clarity using a metric of turbidity. We did obtain water quality data from monitoring stations throughout the watershed that do collect water clarity metrics such as turbidity. However, after further exploration of this data, there were too many “NAs” in the dataset to use and clarity measures that were reported were often from the same site.

A12.3. Edible Flora

We included edible flora in our short list of FEGS due to scoping and the idea that forest buffers could contain edible plants. However, we did not have access to what species of plants are used in forest buffer BMPs and were unable to quantify this further than suggesting that this could be provided if those who implement the BMP choose to.

A12.4. Pest Predators

We included pest predators in our short list of ecosystem services to quantify because it was highly tied to farmers, and we know that farmers are some of the biggest stakeholders in terms of BMP implementation. Unfortunately, we lacked information on the particular species of highest concern to prioritize for analysis. This FEGS could be revisited when information is available about what type of pests are of most concern. We know that providing different habitats, such as forest and grass buffers on agricultural land, often increases biodiversity, and biodiversity may be generally associated with increases in pest predator supply.

A12.5. Habitat Quality for Brook Trout

Initially we wanted to quantify a metric related to birds and brook trout. We were able to quantify a metric for birds, but we struggled to find a metric for brook trout that would work. We focused on stream temperature as a metric for assessing brook trout habitat quality, however, finding relationships between stream temperature and land use was difficult (Fig. A12.1). We suspect this is due to resolution of land use land cover data and lack of specific data on where BMPs are implemented. Below are basic steps we followed:

1. Use background knowledge/previous work by Fink, 2008 (and the riparian planning tool) as outline for approach.
2. Downloaded stream temperature (C) data from Chesapeake Bay water quality data website for non-tidal streams.
3. Chose HUC12 level for the “smallest” resolution.
4. Total of 146 HUC12 catchments with data available from 2016-2020.
5. Extracted landcover area for each HUC12 in the watershed to determine percent land use for each LULC in each HUC12 area.

6. Determine if relationships between water temp and percent LULC cover exists for any LULCs (Fig. A12.1). None of the land covers has an R^2 over 0.1.

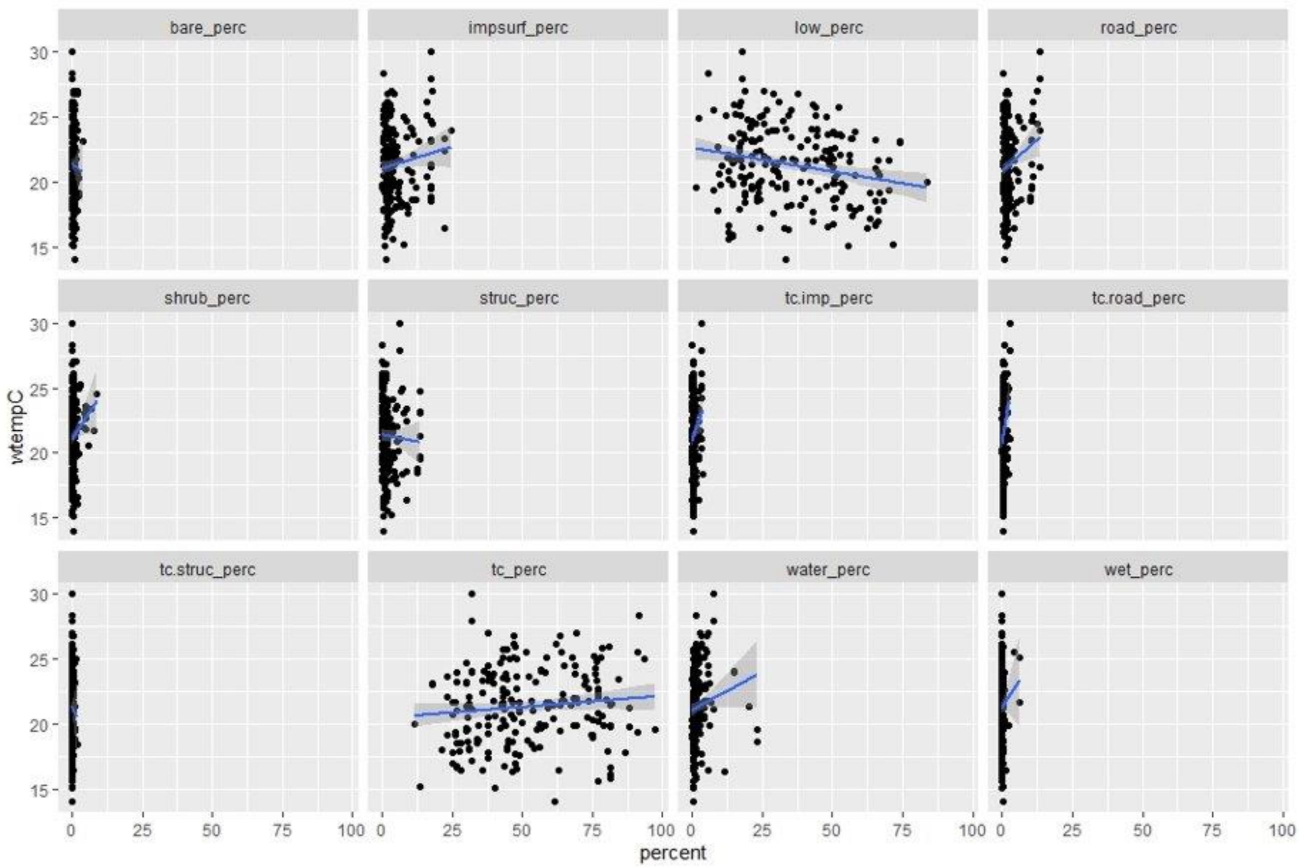

Figure A12.1. Stream water temperature (C) plotted against percent LULC cover. Each tile corresponds to one land use category.

References

Fink, D. B. 2008. Artificial shading and stream temperature modeling for watershed restoration and Brook Trout (Salvelinus fontinalis) management. Master's thesis. James Madison University, Harrisonburg, Virginia

Riparian planning tool: https://www.landscapepartnership.org/maps-data/gis-planning/gis-tools-resources/riparian-restoration-decision-support-tool-1/riparian-restoration-decision-support-tool

Appendix B. Watershed Agreement Outcomes Not Included

B1. List of Watershed Agreement Outcomes Not Included in this Report

Table B1. List of Watershed Agreement outcomes not included in this report and reason for not including.

WATERSHED OUTCOME	DESCRIPTION	WHY WAS THIS OUTCOME NOT INCLUDED?
2017 WATERSHED IMPLEMENTATION PLANS (WIP)	By 2017, have practices and controls in place that are expected to achieve 60 percent of the nutrient and sediment pollution load reductions necessary to achieve applicable water quality standards compared to 2009 levels.	This outcome was excluded because the deadline for this objective (2017) had already passed when this research project began.
BLUE CRAB MANAGEMENT	Manage for a stable and productive crab fishery including working with the industry, recreational crabbers and other stakeholders to improve commercial and recreational harvest accountability. By 2018, evaluate the establishment of a Bay-wide, allocation-based management framework with annual levels set by the jurisdictions for the purpose of accounting for and adjusting harvest by each jurisdiction.	This outcome was excluded because none of the BMPs we have focused on are tied to management of the blue crab fishery.
DIVERSITY	Identify stakeholder groups not currently represented in leadership, decision-making or implementation of current conservation and restoration activities and create meaningful opportunities and programs to recruit and engage these groups in the partnership's efforts.	This outcome was excluded because we found it difficult to consider a direct link between the BMPs and this outcome based on its description which is focused on identifying groups not represented in decision-making or implementation and creating opportunities to do so.
ENVIRONMENTAL LITERACY PLANNING	Each participating Bay jurisdiction should develop a comprehensive and systemic approach to environmental literacy for all students in the region that includes policies, practices and voluntary metrics that support the environmental literacy Goals and Outcomes of this Agreement.	This outcome was excluded because it is difficult to consider a direct link between developing a comprehensive and systemic approach to environmental literacy from implementing BMPs.

WATERSHED OUTCOME	DESCRIPTION	WHY WAS THIS OUTCOME NOT INCLUDED?
FISH PASSAGE	Continually increase access to habitat to support sustainable migratory fish populations in Chesapeake Bay freshwater rivers and streams. By 2025, restore historical historic fish migratory routes by opening an additional 132 miles every two years to fish passage, with restoration success indicated by the consistent presence of alewife, blueback herring, American shad, hickory shad, American eel and brook trout, to be monitored in accordance with available agency resources and collaboratively developed methods.	This outcome is focused on restoring historical fish migratory routes which is related to other BMPs not included in this report (e.g., stream restoration) so we did not include it for the BMPs we focused on.
LAND USE OPTIONS	By the end of 2017, with the direct involvement of local governments or their representatives, evaluate policy options, incentives and planning tools that could assist them in continually improving their capacity to reduce the rate of conversion of agricultural lands, forests and wetlands as well as the rate of changing landscapes from more natural lands that soak up pollutants to those that are paved over, hardscaped or otherwise impervious. Strategies should be developed for supporting local governments' and others' efforts in reducing these rates by 2025 and beyond.	This outcome was excluded because the description of this outcome includes "by the end of 2017" so we felt this outcome was already addressed.
LOCAL LEADERSHIP	Continually increase the knowledge and capacity of local officials on issues related to water resources and in the implementation of economic and policy incentives that will support local conservation actions.	This outcome was excluded because the description of this outcome is focused on increasing knowledge of local leaders and BMP implementation does not necessarily do that; however this report may contribute to this outcome.
MONITORING AND ASSESSMENT	Continually monitor and assess the trends and likely impacts of changing climatic and sea level conditions on the Chesapeake Bay ecosystem, including the effectiveness of restoration and protection policies, programs and projects.	This outcome was excluded because it is focused on monitoring changes due to climate and sea level rise, not necessarily BMPs.

WATERSHED OUTCOME	DESCRIPTION	WHY WAS THIS OUTCOME NOT INCLUDED?
STUDENT	Continually increase students' age-appropriate understanding of the watershed through participation in teacher-supported, meaningful watershed educational experiences and rigorous, inquiry-based instruction, with a target of at least one meaningful watershed educational experience in elementary, middle and high school depending on available resources.	This outcome was excluded because it was not clear if BMP implementation could be a part of an engaging watershed experience for students (based on the outcome description).
TOXIC CONTAMINANTS RESEARCH	Continually increase our understanding of the impacts and mitigation options for toxic contaminants. Develop a research agenda and further characterize the occurrence, concentrations, sources and effects of mercury, PCBs and other contaminants of emerging and widespread concern. In addition, identify which best management practices might provide multiple benefits of reducing nutrient and sediment pollution as well as toxic contaminants in waterways.	This outcome was excluded because it is focused on developing research and characterizing presence of toxics in the watershed and therefore is not necessarily related to implementing BMPs.
WATER QUALITY STANDARDS ATTAINMENT AND MONITORING	Continually improve the capacity to monitor and assess the effects of management actions being undertaken to implement the Bay TMDL and improve water quality. Use the monitoring results to report annually to the public on progress made in attaining established Bay water quality standards and trends in reducing nutrients and sediment in the watershed.	This outcome was excluded because it is focused on improving capacity to monitor, which is not necessarily associated with BMP implementation but more general monitoring in the watershed and monitoring of BMPs after implementation.
SUSTAINABLE SCHOOLS	Continually increase the number of schools in the region that reduce the impact of their buildings and grounds on their local watershed, environment and human health through best practices, including student-led protection and restoration projects	This outcome was excluded because it is unclear whether BMPs we focused on could be implemented at schools and have students involved in the implementation.

WATERSHED OUTCOME	DESCRIPTION	WHY WAS THIS OUTCOME NOT INCLUDED?
CITIZEN STEWARDSHIP	Increase the number and diversity of trained and mobilized citizen volunteers with the knowledge and skills needed to enhance the health of their local watersheds.	This outcome was excluded because it is focused on increasing the number of trained volunteers and it is unclear if that could be a byproduct of BMP implementation. It is possible that identifying links to ecosystem services promotes stewardship but we need evidence.
FORAGE FISH	Continually improve the Partnership's capacity to understand the role of forage fish populations in the Chesapeake Bay. By 2016, develop a strategy for assessing the forage fish base available as food for predatory species in the Chesapeake Bay.	This outcome was excluded because the goal is to understand the role of forage fish and the focal BMPs for this report do not seem directly related to that.
LAND USE METHODS AND METRICS DEVELOPMENT	Continually improve our knowledge of land conversion and the associated impacts throughout the watershed. By December 2021, develop a watershed-wide methodology and local-level metrics for characterizing the rate of farmland, forest and wetland conversion, measuring the extent and rate of change in impervious surface coverage and quantifying the potential impacts of land conversion to water quality, healthy watersheds and communities. Launch a public awareness campaign to share this information with local governments, elected officials and stakeholders.	This outcome was excluded because it has a deadline of December 2021 so it is already completed. It is also focused on land conversion metrics so our short list of BMPs does not adequately meet the outcome description.

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