# HEALTHY WATERSHEDS FORESTRY TMDL FOREST RETENTION STUDY:

## METHODOLOGY, FINDINGS AND RECOMMENDATIONS

## PHASE I STATUS REPORT

## SEPTEMBER 23, 2015


PROJECT TEAM

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VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY
RAPPAHANNOCK RIVER BASIN COMMISSION
GEORGE WASHINGTON REGIONAL COMMISSION
VIRGINIA WATER RESOURCES RESEARCH CENTER AT VIRGINIA TECH
THE NATURE CONSERVANCY
THE CHESAPEAKE BAY COMMISSION

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For the Project Team,

Greg Evans
Virginia Department of Forestry
Project Manager
September 23, 2015

## Background Leading to the Study Project

The 2014 Chesapeake Bay Watershed Agreement includes outcomes for protecting healthy watersheds, high-conservation priority wetlands, and forestland of highest value for maintaining water quality. To accomplish this, there is agreement among the signatories to use management strategies whose aim is to improve the knowledge of land conversion and associated impacts throughout the Watershed by developing a methodology and metrics to characterize the rate of farmland, forestland and wetland conversion, and by measuring the extent and rate of change in impervious surface coverage. The goal is to provide localities with the tools they will need to quantify potential impacts of land conversion and evaluate policy options, incentives, and planning tools that could continually improve their capacity to reduce the rate of conversion of agricultural lands, forestlands, and wetlands.

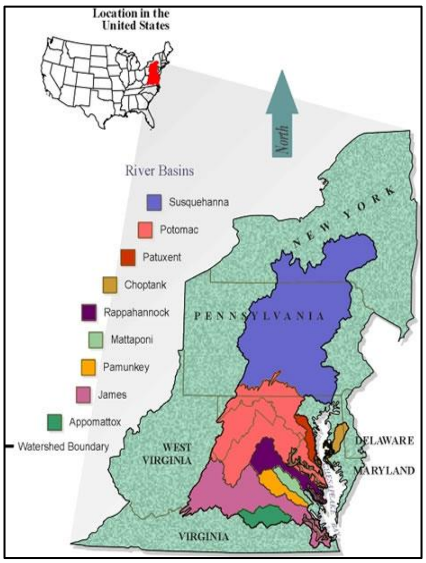



Figure 1 Chesapeake Bay Watershed

Throughout the Watershed, it is projected that the majority of future growth will result from development of agricultural and forest lands into residential and commercial urban uses. In Virginia, to account for this growth in urban land, a load balancing approach was developed. It uses the allocation loads for forest, cropland, pasture, and hayland in the Chesapeake Bay Program's Phase 5.3 Watershed Model for determining Total Maximum Daily Loads (TMDL) of nitrogen, phosphorous, and sediments to calculate the average pollutant loads from a generic pre-development acre based on the mix of land available to be developed in Virginia's portion of the Chesapeake Bay Watershed. To meet TMDL requirements, the post-development land use must be treated with sufficient best management practices (BMPs) to meet the nutrient-neutral pre-development loads of nitrogen, phosphorus, and sediments.

The study partners: the Virginia Department of Forestry (VDOF), the Virginia Department of Environmental Quality (VDEQ), the Rappahannock River Basin Commission (RRBC), George Washington Regional Commission (GWRC), The Nature Conservancy, the Chesapeake Bay Commission and the Virginia Water Resources Research Center (VWRRC) hypothesized that retaining more forestland will protect and enhance healthy watersheds by reducing nitrogen, phosphorus, and sediment loads, thereby reducing the slope of the current TMDL 2025 projections for localities within the Chesapeake Bay Watershed. Therefore, if (1) localities, private land owners, and others take actions to retain forestland and those actions result in a decrease in actual load over the 2025 projected TMDL load allocation land cover; and (2) those decreases subsequently reduce probable future offset costs localities within the region could be facing in 2025, then (3) a way to credit localities and others for retaining forestland now through the Chesapeake Bay TMDL Model should be considered.

This idea was proposed to and supported in concept by the EPA Chesapeake Bay Program Office and the Healthy Watershed Goal Implementation Team (GIT) of partner organizations responsible for developing the management strategies for restoring the Bay and a two phase pilot project was developed. Phase I was designed to test and prove the concept. It is now largely completed and the working hypothesis has been validated. Phase I's findings are summarized in this report. Phase II will focus on the engagement with localities required to institutionalize and implement the regulatory, policy, and changes in the land-use decision process required to achieve increased forest retention throughout the Bay Watershed.

The study findings will be shared with 1) local government officials in the study area to inform their decision making as it pertains to development patterns and forest retention; 2) state officials for consideration in milestone planning and attainment of Chesapeake Bay Watershed Agreement Outcomes; and 3) Bay Program officials to help inform the suite of growth models and advance efforts to account for and credit forest retention actions. It is the goal of the partners that this "proof of concept" effort can provide encouragement for further study of public policy-sponsored forest retention efforts and lead to adoption of a forest retention BMP recognized by the Chesapeake Bay TMDL Model.

## Correlation with 2014 Chesapeake Bay Watershed Agreement Stated Goals and Outcomes

Although forest cover is recognized as one of the best land uses for achieving Chesapeake Bay water quality and healthy watershed goals and outcomes, localities in the watershed have long maintained that unless TMDL credit is given for retaining forestland, there is little local incentive for preserving it. This project addresses that issue. The goal was to build the technical and modeling evidence needed to stimulate negotiation of regulatory and policy changes at the federal, state, and local levels necessary to drive land use planning and decisions in directions that sustain and maintain forestland and thereby further preserve currently healthy watersheds. An objective is to determine the present economic value implications of the reduction in nitrogen, phosphorus, and sediment loads of alternative land-use change scenarios and pass that value on to localities as a forestland BMP in the TMDL model to create an incentive for local officials to retain more high-conservation-value forestland now.

The project has been designed to advance implementation of several cross-goal benefits identified in the Chesapeake Bay Program's Healthy Watersheds Management Strategy and to create collaboration opportunities with other Chesapeake Bay Program Goal Implementation Team (GITs) stated goals and outcomes to minimize the effect of potential barriers to success. Proving the value of a forestland retention BMP in the TMDL model along with the creation of a toolbox of incentives that can be used to stimulate forestland retention throughout the watershed are principle objectives of the project. It also supports the following priorities of other Goal Implementation Teams:

1. The Protected Lands Management Strategy language related to crediting conservation: "Land conservation is not credited towards reductions in the Bay jurisdictions' annual pollution reduction progress reporting. However, land conservation may be able to generate credits for use in compliance trades and/or as offsets for new loads. There may also be opportunities to quantify and incorporate conservation practices into the Chesapeake Bay Program decision

support system and to explore how land use projections might be used to quantify future pollutant load reduction incentives for land conservation";

2. The Water Quality Goal Implementation Team's efforts to meet the Watershed Implementation Plan (WIP) and Water Quality Standards Attainment & Monitoring Outcomes associated with meeting the goals of the Chesapeake Bay Total Maximum Daily Load (TMDL); as well as the desired outcomes for its Riparian Forest Buffer and Urban Tree Canopy strategies;

3. The Vital Habitat Goal Implementation Team's call for cooperation in listing and maintaining a network of land and water habitats that support priority species, water quality, recreational uses, and scenic values;

4. The Stewardship Goal Implementation Team's strategy of promoting individual stewardship, supporting environmental education, protected lands and assisting citizens, communities, and local governments in undertaking conservation initiatives in the Bay region; and

5. The Enhancing Partnering, Leadership and Management Goal Implementation Team's Local Leadership Management Strategy objective to increase the knowledge and capacity of local officials on issues relating to water resources and the implementation of economic and policy incentives that support local conservation actions.

## Project Design

### Study Area

The Rappahannock River Basin was selected as the project study area to serve as a proxy for the Chesapeake Bay Watershed. The reasons for this choice were because the basin mirrors most of the attributes of the Chesapeake Bay Watershed, e.g.:

- Geography: headwaters to coast
- Land Use: forest, agriculture, urban, rural
- Areas of high-density development growth
- Rappahannock River Basin Commission (RRBC) consisting of local government leaders and VA General Assembly members with long, active leadership history promoting innovative approaches for meeting water quality goals
- Basin is 100 percent in Virginia so watershed issues outside of Virginia control are minimal (other than air)

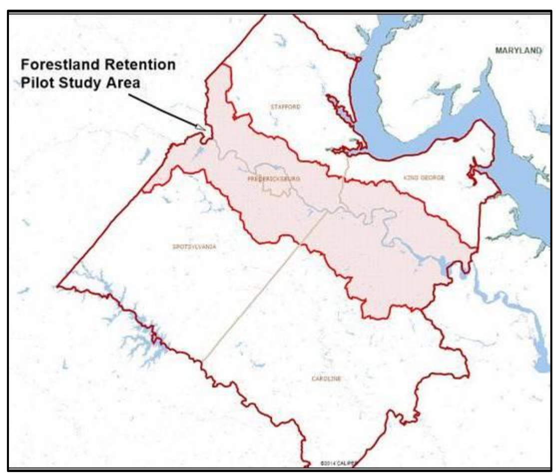



Figure 2 Rappahannock River Basin

# Project Phasing

## Phase I

The portion of the basin encompassed by the George Washington Regional Commission's (GWRC) service area was selected for the Phase I proof-of-concept alternative growth scenario modeling study for cost reasons and because it served well as a microcosm of the Rappahannock River Basin sharing many of the same attributes as the basin at-large, including a strong commitment to water quality leadership through the GWRC.

The objective of Phase I was to model various land use scenarios as a proof-of-concept pilot using EPA/TMDL model methodologies and land use data provided by the GWRC localities to determine if forest retention actions by individual localities would result in a decrease in actual load over their current 2025 projected TMDL load allocation land cover. If "yes", the modeling data and assumptions would be shared with EPA and localities to determine the present economic value implications of the reduction in nitrogen, phosphorus, and sediment loads of alternative land-use-change scenarios. A Chesapeake Bay watershed-wide methodology and local level metrics could then be developed. Once done, the value could be passed on to localities as a forestland retention BMP in the TMDL model to create an incentive for localities to implement land use policies now to retain more high-conservation-value forestland.

Data collection and scenario modeling was completed July 31, 2015 using different assessments and evaluations of growth trends in the pilot region that paralleled modeling criteria CB staff are using to revise the 2017 CB TMDL model. The effort was done in coordination with Chesapeake Bay (CB) program staff and the GWRC pilot area localities. The scenarios were as follows:

1. The current TMDL 2025 predictions (based on revised 2015 land cover estimates) for the localities in the pilot area;

2. A green infrastructure model that significantly factored in increased forestland retention (i.e. 10% over losses under Scenario 3);

3. A model based on projected land use if pending developments approved for development in accordance with the comprehensive plans for each locality in the pilot area and development proffers were followed and implemented; and

4. A hypothetical scenario that was a hybrid between (2) and (3) which postponed 50 percent of projected forest loss from long-term development until the post-2025 era.

In addition, 2010 and 2015 scenarios were also run to identify trends.

The results of the alternative development model scenario runs confirmed the water quality and healthy watershed value of forestland retention and demonstrate that a range of potential offsets are possible depending on the investment made early in BMPs that retain forestland. Summary tables for each jurisdiction are included in the Methodology and Findings section of this report. Quantification of the offset economic values demonstrated possible savings of $125 million depending on the land use planning decisions made and will be used to inform discussions with local government leaders, EPA, and pertinent Chesapeake Bay Program Goal Implementation Teams.

Concurrently with the scenario modeling work, the Virginia Water Resources Research Center at Virginia Tech has conducted an independent review and synthesis of the literature regarding ecosystem services related to water-quality protection and remediation provided by forests. This review looked at the specific attributes of forestland that contribute to those ecosystem services to provide information for prioritization of forestland retention decisions in the pilot area. Evaluation of spatial variability and landscape position of water-related ecosystem services provided within classifications of forestland was considered as part of the literature review. This will help in determining which forest areas (e.g., headwaters, upland, lowland, riparian, etc.) in Virginia's diverse geomorphic regions offer the greatest value if retained or otherwise protected from development. The information along with the model scenario run results will be used in Phase II to inform negotiations and discussions with local leaders.

## Phase II

Phase I will lead into Phase II when all findings and recommendations to-date are presented to EPA, the Healthy Watershed GIT and to local elected and appointed leaders in the Rappahannock River Basin in a summit scheduled for September 23, 2015 sponsored by the Rappahannock River Basin Commission. A workshop at the summit will be structured to begin discussions with local officials on strategic implementation strategy next steps including policy, incentives and land use planning approaches that would be tested and if successful, captured to create the basis for the tool box that could be incorporated into the planned Chesapeake Bay Program on-line repository and used by all the jurisdictions in the Chesapeake Bay watershed.

Outreach to and negotiation with local government leaders in coordination with the Rappahannock River Basin Commission (RRBC), EPA and the pertinent Chesapeake Bay Program GITs will be the focus of Phase II and would extend the project from its current pilot area in the George Washington Regional Commission service area of the basin to the entire Rappahannock River basin as a proxy for the Chesapeake Bay watershed.

Since land use decisions are largely local, it is very important that the forestland retention incentives tool box be built from a bottom up rather than a top down perspective. The components have to be credible on a peer to peer basis and they have to be designed to help local officials optimize land use decisions so development can occur at the same time that water quality protection actions are maximized.

The project sponsors will work extensively through the RRBC, with local government officials within the Basin, as well as with the Chesapeake Bay Program's Local Government Advisory Committee (LGAC) and other GITs to develop the tool box of criteria, incentives, etc. that could be used in land use policy and zoning situations to accurately identify and assign appropriate values to high conservation value forest lands. The forest land TMDL best management practice credit would be the driver but only one of what could be a package of incentives available.

## Phase I Methodology and Findings

The alternative land use scenario modeling study focused on the portion of the Rappahannock River Basin within the George Washington Regional Commission service area to assess growth trends in the region and evaluate the spatial variability of forest ecosystem service value. The Virginia Department of Environmental Quality and the George Washington Regional Commission coordinated with federal Chesapeake Bay Program modelers to develop alternative future development scenarios to represent the range of potential policy approaches to forestland retention in the rapidly developing GWRC region. By simulating the loading impact of the alternative development scenarios and comparing the cost of additional urban BMP implementation to offset the loads, the project was planned to demonstrate the cost-benefit relationship of forestland retention.

The objective was to assess growth trends in the Rappahannock River Basin, George Washington Regional Commission service area to determine the rates of conversion for agriculture and forest and the mix of pervious and impervious lands resulting from that conversion. The intent was to ascertain whether different land development scenarios, which reflect the effect of both private conservation actions and new public policy action (e.g. having the effect of slowing or even reversing the rate of loss of forested lands and urban tree canopy), along with requiring urban BMPs on all new development, could result in enough forecasted pollutant load reductions that might offer a potential cost off-set to local governments over more traditional public investments in "grey infrastructure" to clean up the Chesapeake Bay and its tributaries.

The study has produced a regional demonstration of how alternative development methods that increase high-value forestland retention can help reduce the offset requirements of development. This could in turn reduce BMP treatment costs needed to comply with Virginia's nutrient-neutral stormwater regulations, while maximizing the ecosystem services provided by forests.

One-meter resolution land cover data (even, perhaps, enhanced with LIDAR data to measure hidden impervious area underneath the imagery-detected tree canopy) are expected in 2017 to become the basis for determining urban/suburban land covers and monitoring land cover changes over time in the revised Bay TMDL model. To mimic the accuracy of such high resolution data to the maximum degree possible, the project partners coordinated with EPA program personnel to use datasets complementary to those used for the EPA Chesapeake Bay Model to create synthetic estimates and forecasts of land cover that reflect:

- A synthesis of historic rates of land cover change,
- Current estimates of forest cover by riversegmentshed and by locality,
- Assumptions of urban BMP installations with any impervious surface area growth, and

- Consideration of the growing inventory of conserved lands (under various public, non-profit and private control) and easements, which will preserve existing forests.

## A. Methodology: Data Collection

Necessary data inputs from local governments within the pilot study area included:

a) Current local parcel GIS polygon datasets (.shp), indicating parcel improvement status, zoning, acreage, parcel ownership information, year structure built

b) Subdivision GIS polygon datasets, with subdivision name and number of improved and current vacant lots.

Data inputs from the USGS/Chesapeake Bay Program, the Virginia Department of Environmental Quality and the Virginia Department of Conservation and Recreation included:

a) Confirmed Rappahannock River Basin  riversegmentshed GIS polygon files (.shp)

b) Estimated acreages and change rates by 5-year period (1995-2000, 2000-2005, 2005-2010, and 2010-2015) for all major land cover categories of the BayFAST model for each riversegmentshed of the Rappahannock River basin in PD 16

c) Projection data[1], for each land cover type for 2020 & 2025 by riversegmentshed by locality for the Rappahannock River basin (GWRC service area part)

d) Urban BMP inventory by riversegmentshed

e) Latest conservation easement and conserved lands .shp layers for PD 16 (see Figure 2)

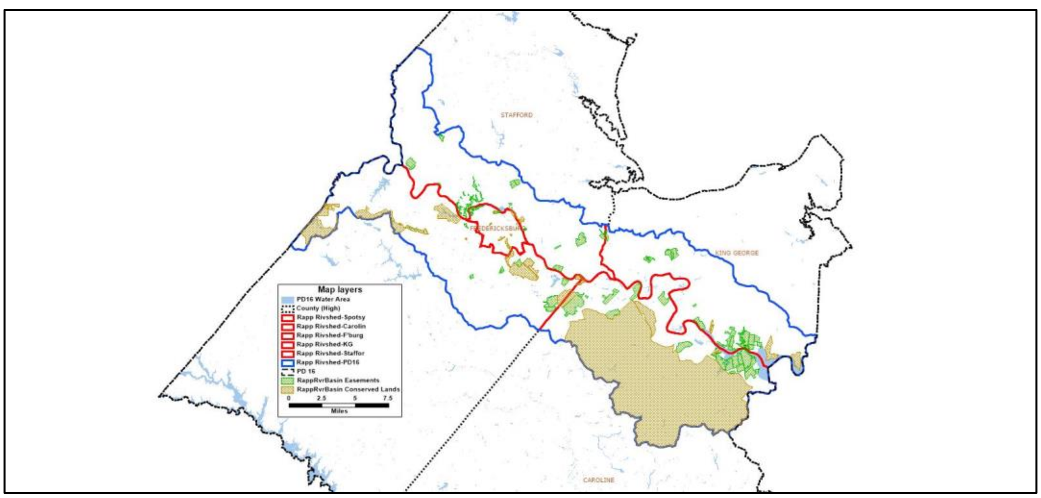



**Figure 3. Conserved and Easement Lands in Rappahannock River Watershed**

[1] Land use data estimated both before & after BMPs are applied to the land, since some BMPs convert projected agricultural or urban lands to forest. Both versions for each year are available.

Data inputs from the GWRC included:

a) Socio-Economic (Population & Employment) 2005 Estimates and 2035 Projections by Traffic Zone from 2035 Constrained Long-Range Transportation Plan (CLRTP)

b) Socio-Economic (Population & Employment) 2010 Estimates and 2040 Projections by Traffic Zone from 2035 CLRTP

Data inputs from within the pilot study area from Google Earth included:

a) 2013 color photography imagery for delineation of existing forestry coverage polygons

## B. Methodology: Data Preparation

1. <u>Data Cropping</u>: used GIS to crop various spatial (ArcGIS .shp) files to the Rappahannock River Watershed area in PD 16

2. <u>Geo-tagging</u>: used GIS to assign all area polygon data (e.g. parcels, subdivisions, conservation easements, conserved lands, traffic zones, forestry cover polygons, etc.) to the corresponding riversegmentshed and locality (FIPS)

3. <u>Digitizing</u>: created existing forestry polygons to obtain acreage value

4. <u>Interpolation</u>: used to define 2010 base year, 2015 current condition and 2025 horizon year data by traffic zone (applied to riversegmentsheds) for “business as usual” (decentralized) and “community plans” scenarios.

5. <u>Overlay</u>: done to determine the impact of existing approved subdivisions and PUDs on the forestry cover layer and determine the amount of forest cover throughout the watershed and by riversegmentshed that is already under a form of conservation protection.

# Scenario Modeling

The Virginia Department of Environmental Quality (VDEQ) was responsible for modeling the various development scenarios. The BayFast[2] scenario model was used to compute the water quality (and associated pollution abatement cost) effects of different land cover scenarios selected by the project team. These scenarios were:

a) revised TMDL 2025 predictions (applying 2015-2015 TMDL growth rates to revised 2015 land cover estimates) by sub-watershed and aggregated for the localities in the pilot area,
b) a green infrastructure model that factored in increased forestland retention (i.e. preserving 10% more forest than the losses forecast under Scenario 3),

[2] For more information on BayFast model, see: http://www.bayfast.org/About.aspx

c) a model based on projected land cover if pending projects approved for development in accordance with the comprehensive plans for each locality in the pilot area and development proffers and open space preservation guidelines were followed and implemented; and
d) a “phased development impact” scenario that was a hybrid between (2) and (3) by assuming postponement of 50 percent of the projected forest loss from long-term development described under Scenario 3 until the post-2025 era.
e) In addition, for comparison purposes and to identify trends, modeling runs based on EPA’s TMDL model methodology were run for 2015.

To initiate the BayFAST simulation, facilities were created to delineate the Rappahannock River Basin portion of each locality (Caroline, Fredericksburg, King George, Spotsylvania, and Stafford). The land use data from the BayFAST Scenario Development Templates representing each scenario was then used to create a unique facility-land use representing each scenario in each locality. Where necessary, the general land use classes (e.g. pervious) in the templates were broken out to the detailed land use classes (e.g. regulated pervious and unregulated pervious) needed in BayFAST based on the proportions of the detailed land classes in the Bay model 2015 land use. Each scenario was run in a “no action” state meaning they assumed no BMPs were present.

The BayFAST scenario model templates were:

a) Decentralized/”Business as Usual”: interpolated 2010-2025 population and employment growth trends by riversegmentshed from the 2035 CLRTP to historic rates of land cover conversion for each riversgementshed.

b) Community Plans: land cover conversions resulting from all rezoning and planned unit developments approved by local governments in conformance with local comprehensive plan.

c) Greenprint Scenario 1: preserves 10 percent more of the forest lost under the land cover conversion projected under the decentralized/”Business as Usual” scenario.

d) Greenprint Scenario 2: preserves 50 percent of the projected forest cover lost from long-range build-out development projects until after 2025 horizon year.

## 2015 Local Land Cover Estimates

The method of developing local estimates by land-river segmentshed varied by locality, based (in part) on the availability of local spatial (GIS) data files. To avoid repetition of the list of GIS data files provided and used (to varying degrees), they are summarized in the following tables.

**Table1. 2015 Local Land Cover Estimates**

| Locality | Tax Parcels | Subdivision Borders | Zoning | RPA Border | Conservation Easements | Federal, State & Local Lands | Water Areas | Tree Canopy | Land Use |
|---|---|---|---|---|---|---|---|---|---|
| City | • | • | • | • | DCR | • | • | • | • |
| Caroline | • | • | • | • | DCR | • | • | | |
| King George | • | • | • | • | DCR | • | • | | |
| Spotsylvania | • | • | • | • | DCR | • | • | | |
| Stafford | • | • | • | • | Local/DCR | • | • | | • |

**Table 2. Components of Impervious Surface Area Layer**

| Locality | Components of Impervious Surface Area Layer | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Actual Layer | Street Centerlines | Street ROW | Driveways | Sidewalks | Building Footprints | Parking Lots | Pools & Hard Courts | Other |
| City | 1. | | | | | • | | | |
| Caroline | | • | • | | | • | | | |
| King George | | • | • | • | • | • | ○ | ○ | |
| Spotsylvania | | • | • | • | • | • | • | • | ○ |
| Stafford | 2. | • | • | • | • | • | • | • | • |

- • = locally-provided
- ○ = calculated by RDS, LLC

1. Impervious area included in urban tree canopy study (2010) based on summer, 2008 1-meter NAIP imagery classified by VDOF imagery analyst Jim Pugh.
2. Impervious layer created by Stafford Co. by converging multiple spatial data layers, including: airports, athletic courts, bridges, buildings, concrete slabs, open storage, paved driveways, paved medians, paved parking, pools, paved roads, public sidewalks, (storage) tanks, unpaved driveways, unpaved roads, unpaved parking.

The process of developing a "current/2015" land cover estimate for each locality and each land-riversegmentshed area is summarized below.

## A. City of Fredericksburg

The City[3] is completely encompassed by and unique in the study area due to the existence of a land cover/urban tree canopy (UTC) spatial dataset[4]. This file represents a study performed by the Virginia Department of Forestry (VDOF) in 2010, based on summer 2008 one-meter imagery. This dataset, provided by VDOF as a GIS data layer, provided an excellent starting point for identifying necessary updates. Overlaying this GIS layer on the current (2014) Google Maps and/or Microsoft Bing high-resolution imagery, combined with updated reference layers from the City, produced an updated layer that reflected new development in the City since the original 2008 imagery was taken as well as land cover conversions (e.g. building demolition reverting to open space).

Updated GIS layers (e.g. building footprints) provided by the City were merged with the Urban Tree Cover (UTC) land cover file to confirm current building impervious areas. These included adding new buildings constructed by the University of Mary Washington and other private development interests as well as identifying older buildings which have been removed reverting the impervious area to pervious open space. In addition, paved additions to the City bike trail system, public and private parking areas, City-defined paved ROW and other available impervious feature layers were added to enhance the non-building impervious layer. Pre- and post-updated land coverage for the City as a whole is shown in the following table.

**Table 3 City of Fredericksburg Land Cover**

| Land Cover | Total Acres: Pre-Update (2008) | Total Acres: Post-Update (2015) | Update: Net Difference (+/-) |
|---|---|---|---|
| Building Impervious | 463 | 604 | 141 |
| Non-Building Impervious | 1,658 | 1,597 | -61 |
| Non-tree Vegetation | 1,609 | 1,512 | -36 |
| Tree Canopy | 2,979 | 2,981 | 2 |
| Water | 55 | 73 | 18 |
| **Total** | **6,754** | **6,828** | **64** |

Source: Va. Dept. of Forestry, "A Report on Fredericksburg's Existing and Possible Urban Tree Canopy", (Virginia Tech, 2010); and Regional Decision Systems, LLC, 2015.

[3] Containing 6,771.67 acres in land area and 24,286 persons in 2010.
[4] Land cover types include: building impervious, non-building impervious, non-tree vegetation, tree canopy, and water.

The enhanced land cover polygon file was then queried to obtain aggregate updated land cover estimates for each of the three land-riversegmentshed areas within the City of Fredericksburg.

## B. General Methodology for Current Land Cover for County Areas

Each County's tax parcel file was cropped to create a land cover workfile covering the Rappahannock River watershed area of each County. Several attribute columns were added to the workfile, including land/riversegmentshed ID, acres, and (land) cover class (to store the description of the RDS-determined current land cover on the parcel). The workfile was then viewed in the GIS with Google Maps (Hybrid view) imagery (2014) as a background image and parcel boundaries were merged, adjusted, deleted or otherwise modified to conform to a close approximation of the dominant land cover pattern for the immediate area and the project area as a whole. This operation provided a vector polygon file for the approximate boundaries between land cover types. This vector boundary file is useful to identify the areas (and amount of protection) provided by existing RPA, conservation and riparian easement boundaries described by other GIS vector polygon datasets.

For parcel lots in subdivisions adjoining forested areas where the forest appeared to cover a significant portion of the back or side yard of a property, the areas taken up by the house, out-buildings, scattered trees and yard were coded as "pervious", whereas the denser, tree-covered area of the lot was described as "forest". Water bodies were digitized and coded as "water along with stream channels (where the imagery reflected a transition in vegetation pattern from wetland to upland vegetation).

The resulting aggregate area for each land cover type (e.g. forest, pervious, construction, extraction) was then adjusted (reduced) to take into account the existence of impervious area (i.e. building footprint area + public road paved roadway[5] and other impervious features) within the aggregate area covered by each land cover type.

Finally, each land cover record was coded for being partially or wholly located in the County RPA, a conservation easement or affected by considerations affecting future development potential.

[5] Unless defined by locally-supplied GIS layer, paved roadway was estimated by multiplying the study area's (and for each land-riversegmentshed area) aggregate length (miles) of road centerline x 5280 ft. = total linear feet, times the number of lanes (2-lane assumed for all roads, except US Rt. 301 and St. Route 3, which were coded as 4-lane), x 10 ft. per lane = total square feet of paved road surface, which was then divided by 43,560 sq. feet per acre = total acres of paved roadway.

## C. Unique Methods or Assumptions by County

### 1. *Caroline County*

The study area (75,546.05 acres) covers 21.89 percent of the County land area (344,960 acres) and includes 1,889 persons (6.6 percent of the County population (2010). Most of the study area is covered by portions of Fort A. P. Hill and is under federal government jurisdiction.

Ideally, if the data had been available, such features as driveways, sidewalks, parking lots and other surfaces would have been included. For this portion of the study area, driveway surface area was estimated based on the average length of driveways observed in King George County and multiplied by the number of residences within the Caroline study area and the assumed width of 10 feet per driveway. Otherwise, due to budgetary limitations and the comparative rural nature of the Caroline portion of the study area, these elements were not included.

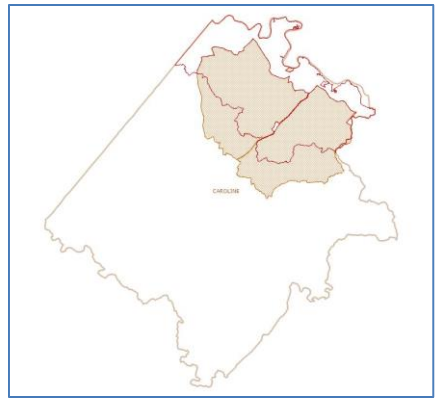


Figure 4. Caroline County Study Area

### 2. *King George County*

The study area (45,644.64 acres) covers 37.9 percent of the County land area and includes 6,817 persons (28.9 percent of the County 2010 population).

The provided sidewalk centerline file was enhanced by manually digitizing (from Google Maps 2014 imagery) additional sidewalks in the Hopyard subdivision as well as other developed areas (e.g. near County courthouse). The sidewalk and driveway centerline (polyline) layers were converted to polygon files by using a 2 ft. buffer for sidewalks and 10 ft. buffer to define driveway areas.

Figure 5. King George County Study Area

### 3. *Spotsylvania County*

The study area (60,004.78 acres) covers 22.75 percent of the County land area (263,680 acres) and includes 86,197 persons (70.4 percent of the County 2010 population).

The County GIS department provided many spatial data layers which were merged to create an impervious surface layer generally comparable to the layer provided by Stafford County.

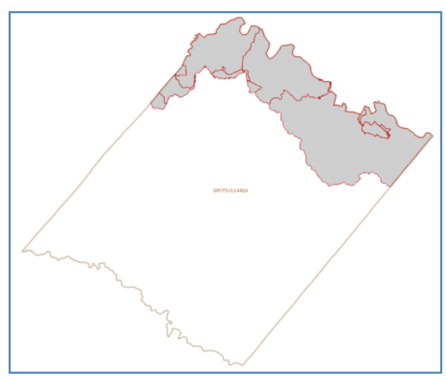


Figure 6. Spotsylvania County Study Area

***4. Stafford County***

The study area (52,390.15 acres) covers 29.2 percent of the County land area (179,200 acres) and includes 42,092 persons (32.6 percent of the County 2010 population).

The County GIS department provided detailed impervious surface layer (2013-2014 vintage) which, when combined with building footprint area, provides a very accurate estimate of this land cover.   The shape and extent of the other land cover types were determined by adjusting parcel lines to approximate the land cover outlines shown on Google and Bing maps imagery.

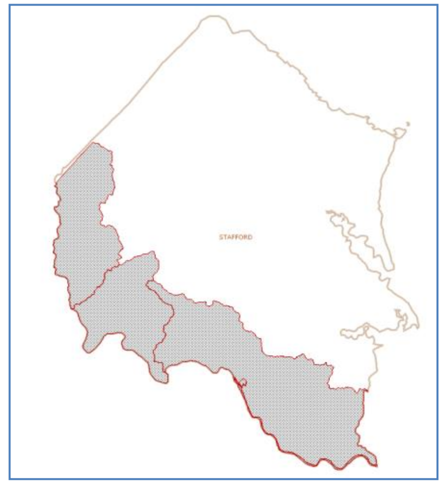



**Figure 7. Stafford County Study Area**

# Forecasting Land Cover Change: 2015 – 2025

## A. Supporting Demographic Assumptions

Absent natural catastrophes such as wildfire, flood and tornadoes; land cover conversion is mostly a result of human actions through the land development process in response to economic and population growth. Consequently, it is necessary to understand how much development demand is expected to drive future land conversion.  The sub-jurisdictional, sub-watershed population and economic forecasts used for this study are taken (depending on the scenario used) from the GWRC/FAMPO 2035 or 2040 Constrained Long-range Transportation Plans (CLRTP). However, these forecasts are based, in part, on GWRC's analysis of other demographic and real estate market factors, such as changing family and average household size, rates of housing stock absorption, commercial space vacancy rates, etc.

**Table 4.  2010 Household Population Data by Jurisdiction**

| Jurisdictions in Study Area | 2010 Census | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total Population | Household Population | Total Housing Units | Occupied Housing Units | Vacant Housing Units | Housing Vacancy Rate | Average Household Size |
| Caroline Co. | 1,889 | 1,619 | 727 | 644 | 83 | 11.42% | 2.514 |
| Share of Study Area | 1.17% | 1.04% | 1.21% | 1.15% | 2.22% | | |
| Fredericksburg, City of | 24,286 | 21,655 | 10,442 | 9,484 | 958 | 9.17% | 2.283 |
| Share of Study Area | 15.06% | 13.88% | 17.44% | 16.90% | 25.64% | | |
| King George Co. | 6,817 | 6,657 | 2,551 | 2,320 | 231 | 9.06% | 2.869 |
| Share of Study Area | 4.23% | 4.27% | 4.26% | 4.13% | 6.18% | | |
| Spotsylvania Co. | 86,197 | 84,101 | 30,657 | 29,038 | 1,619 | 5.28% | 2.896 |
| Share of Study Area | 53.45% | 53.91% | 51.21% | 51.73% | 43.32% | | |
| Stafford Co. | 42,092 | 41,966 | 15,488 | 14,644 | 846 | 5.46% | 2.910 |
| Share of Study Area | 26.10% | 26.90% | 25.87% | 26.09% | 22.64% | | |
| **GWRC - Rappahannock Watershed** | **161,281** | **155,998** | **59,865** | **56,130** | **3,737** | **6.24%** | **2.791** |
| | | | | | | | |
| Source: Regional Decision Systems, LLC. 2010 Block Statistics, aggregated for study area. | | | | | | | |

## B. Population Projections for PD 16 and Rappahannock Watershed area

The historic rapid population growth of the region and its unique geographic setting midway between the national and Virginia state capitals makes population projection work a difficult challenge. Commonly, population projections continue to extrapolate past growth trends over several decades into the future.  This was the case for projections used for the last 2 CLRTP updates and is generally the method behind the “official” local population projections produced under contract for the Virginia Employment Commission by the Demographics Research team of the Weldon Cooper Center of the University of Virginia.

These forecasts generally fail to consider the dampening effect of the Great Recession era (Dec. 2007 – June 2009) on housing and credit markets and the unexpected extended duration of the housing market’s recovery. Consequently, they are already seen to portray population growth greater than actually measured by their Population Estimates program. To mirror the effect of this slow recovery on the long-term population growth of the study area, the short-term 2010-2014 population growth trend was used to dampen existing “official” forecasts as shown below. These forecasts are believed to represent the “new normal” for continued population growth of the study area for some time to come.

**Table 5. Projected Population Growth by Jurisdiction 2010 - 2030**

| **Total Population** | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline County | 28,545 | 29,727 | 29,973 | 31,400 | 32,423 | 33,447 |
| King George County | 23,584 | 24,739 | 25,347 | 27,109 | 28,553 | 29,997 |
| Spotsylvania County | 122,397 | 126,337 | 144,316 | 166,236 | 195,077 | 223,917 |
| Stafford County | 128,961 | 138,230 | 153,557 | 178,152 | 211,281 | 244,410 |
| Fredericksburg city | 24,286 | 28,213 | 25,466 | 26,647 | 27,515 | 28,383 |
| **GWRC-PD 16** | 327,773 | 347,246 | 378,658 | 429,544 | 494,849 | 560,154 |

| **Group Quarters Population** | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | **2010** | **2014** | **2015** | **2020** | **2025** | **2030** |
| Caroline Co | 513 | 565 | 1,725 | 1,881 | 2,098 | 2,463 |
| King George Co | 301 | 332 | 330 | 333 | 344 | 374 |
| Spotsylvania Co | 524 | 577 | 1,133 | 1,266 | 1,440 | 1,710 |
| Stafford Co | 3,593 | 3,958 | 2,941 | 3,049 | 3,310 | 3,777 |
| City of Fredericksburg | 2,596 | 2,860 | 2,353 | 2,381 | 2,470 | 2,700 |
| **GWRC-PD 16** | **7,527** | **8,292** | **8,483** | **8,911** | **9,660** | **11,024** |

| **Household Population** | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | **2010** | **2014** | **2015** | **2020** | **2025** | **2030** |
| Caroline Co | 28,032 | 29,162 | 28,247 | 29,520 | 30,326 | 30,984 |
| King George Co | 23,283 | 24,407 | 25,016 | 26,776 | 28,209 | 29,623 |
| Spotsylvania Co | 121,873 | 125,760 | 143,184 | 164,969 | 193,637 | 222,208 |
| Stafford Co | 125,368 | 134,272 | 150,616 | 175,103 | 207,971 | 240,632 |
| City of Fredericksburg | 21,690 | 25,353 | 23,113 | 24,265 | 25,045 | 25,684 |
| **GWRC-PD 16** | **320,246** | **338,954** | **370,176** | **420,633** | **485,188** | **549,131** |

**Table 6. Housing Data by Jurisdiction 2010 - 2030**

| **Average Household Size** | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline Co | 2.68 | 2.64 | 2.64 | 2.64 | 2.64 | 2.64 |
| King George Co | 2.78 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 |
| Spotsylvania Co | 2.91 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 |

| Average Household Size | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Stafford Co | 3.00 | 2.95 | 2.95 | 2.95 | 2.95 | 2.95 |
| City of Fredericksburg | 2.28 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 |
| **GWRC-PD 16** | 2.88 | 2.81 | 2.82 | 2.83 | 2.84 | 2.84 |

Note: The estimated 2014 average household size was estimated by regressing the local rates against the national trend from 2010-2014, and then held constant into the future since national demographic experts are undecided about future national trends due to the national debate over immigration policy.

| Occupied Housing Units | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline Co | 10,456 | 11,053 | 10,706 | 11,188 | 11,494 | 11,743 |
| King George Co | 8,376 | 8,918 | 9,140 | 9,783 | 10,307 | 10,824 |
| Spotsylvania Co | 41,942 | 43,897 | 49,979 | 57,583 | 67,590 | 77,563 |
| Stafford Co | 40,869 | 45,462 | 50,996 | 59,287 | 70,415 | 81,474 |
| City of Fredericksburg | 9,505 | 11,295 | 10,297 | 10,810 | 11,158 | 11,442 |
| **GWRC-PD 16** | 111,148 | 120,625 | 131,118 | 148,652 | 170,964 | 193,046 |

| Total Housing Units | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline Co | 11,729 | 12,398 | 12,009 | 12,550 | 12,893 | 13,173 |
| King George Co | 9,477 | 10,090 | 10,342 | 11,069 | 11,662 | 12,246 |
| Spotsylvania Co | 45,185 | 47,291 | 53,843 | 62,036 | 72,816 | 83,560 |
| Stafford Co | 43,078 | 47,919 | 53,752 | 62,491 | 74,221 | 85,878 |
| City of Fredericksburg | 10,467 | 12,438 | 11,339 | 11,904 | 12,287 | 12,600 |
| **GWRC-PD 16** | 119,936 | 130,137 | 141,286 | 160,051 | 183,879 | 207,457 |

| Vacant Housing Stock | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline Co | 1,273 | 1,346 | 1,303 | 1,362 | 1,399 | 1,430 |
| King George Co | 1,101 | 1,172 | 1,201 | 1,286 | 1,355 | 1,423 |
| Spotsylvania Co | 3,243 | 3,394 | 3,864 | 4,452 | 5,226 | 5,997 |
| Stafford Co | 2,209 | 2,457 | 2,756 | 3,204 | 3,806 | 4,404 |
| City of Fredericksburg | 962 | 1,143 | 1,042 | 1,094 | 1,129 | 1,158 |
| **GWRC-PD 16** | 8,788 | 9,537 | 10,367 | 11,753 | 13,517 | 15,263 |

| Housing Units Vacancy Rate | | | | | | |
|---|---|---|---|---|---|---|
| **Jurisdiction** | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Caroline Co | 10.85% | 10.85% | 10.85% | 10.85% | 10.85% | 10.85% |
| King George Co | 11.62% | 11.62% | 11.62% | 11.62% | 11.62% | 11.62% |
| Spotsylvania Co | 7.18% | 7.18% | 7.18% | 7.18% | 7.18% | 7.18% |
| Stafford Co | 5.13% | 5.13% | 5.13% | 5.13% | 5.13% | 5.13% |
| City of Fredericksburg | 9.19% | 9.19% | 9.19% | 9.19% | 9.19% | 9.19% |
| **GWRC-PD 16** | 7.33% | 7.33% | 7.34% | 7.34% | 7.35% | 7.36% |

Table 7 that follows also reflects the updated growth forecasts resulting from the post 2010 growth trends for the whole Middle Basin and the Rappahannock River watershed portion. The locality-level breakdown of the total population for the study area is shown in the detailed data tables in Appendix A.

**Table 7. Population Breakdown by Sub-Area in Pilot Study Area**

| Geography | Sub-Area | Total Population (Household and Group Quarters Combined) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2010 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Middle Basin | Rappahannock River Watershed Area | 161,281 | 182,955 | 188,008 | 213,273 | 245,698 | 295,130 |
| | Rappahannock River Basin Communities | 327,773 | 347,246* | 356,837 | 404,790 | 466,331 | 560,154 |
| | Share of Total Middle Basin Area | 49.21% | 52.69% | 52.69% | 52.69% | 52.69% | 52.69% |

*University of Virginia, Weldon Cooper Center, "Local Population Estimates for July 1, 2014". Note: 2015-2030 "official" population projections have been downward-adjusted by RDS, LLC for consistency with the area growth rates from 2010-2014, and future population growth rates from decade to decade were applied to 2014 base estimate to complete forecast through 2030.

## Scenario Descriptions

### A. Scenario (A) 2025: "Business as Usual/Decentralized Growth"

The approach to forecasting land cover conversion for the first scenario relies heavily on the existing assumptions and results of the Chesapeake Bay land use model, which has been derived from historic trends in land cover conversion at the sub-watershed level, and linear projections of population and economic growth associated with continued urban growth and sprawling development patterns. These forecasting assumptions assume urban development will continue to drive land conversion from forest and farmland/open space to subdivisions, commercial development and significant growth in the urban impervious area coverage. These forecasts also assume that local governments will continue to regulate development in much the same way it always has, without extraordinary efforts to encourage higher densities, tree canopy and forest retention.

Linear interpolation (from the 2010 base year) of the related 2035 long-range projections was used to produce an approximation of development patterns in 2025 at the land-riversegmentshed level by grouping traffic zone–level projections to create sub-watershed forecasts. These forecasts were then related to the existing Bay model land cover forecasts and adjusted to reflect 2010-2015 trends.

### B. Scenario (B) 2025: "Community Plans"

The "Community Plans" scenario was selected for two reasons:

1) The scenario has corresponding small area (traffic zone) socio-economic forecasts which can be aggregated to closely match the sub-watershed areas and provide surrogate forecasts of land conversion from anticipated development, and

2) the scenario is based on the latest adopted local comprehensive plans and all approved development proposals in each locality which anticipate development's need to increasingly deal with Bay-related environmental standards.

### C. Scenario (C) 2025: "Greenprint/Forest Retention"

The Greenprint or Forest Retention scenario represents forecasts of land conversion based on the consideration of the following factors:

1. The relative supply of approved, but undeveloped, residential lots in all the existing subdivisions located in each subwatershed,
2. A calculation of the number of housing units needed and additional households formed to maintain the local markets' average supply of available new housing stock,
3. The land use patterns reflected in the "Greenprint Scenario" (see Appendix A) and corresponding "development avoidance area" developed in the regional Green Infrastructure Plan

In light of the uncertainty regarding to what extent local governments may adopt forest retention policies and the amount of existing forest and tree canopy that could be affected, GWRC researchers arbitrarily developed this scenario using the assumption that 10 percent more forest would be retained than the case under Scenario A.

### D. Scenario (D) 2025: "Phased Development Impact on Greenprint/Forest Retention"

Under this Scenario, in contrast to Scenario B, researchers hypothecated that rather than losing all of the forest acreage from approved development by 2025, the approved developments might, considering the long-term build-out of their projects, pursue a phasing plan for land clearing and eventual development which could postpone 50 percent of the expected forest loss until some date after 2025.

## Interpretation of Phase I Alternative Land Use Modeling Results

The results of the BayFAST scenarios for each locality were evaluated. They clearly demonstrated that the Greenprint Scenario C, where historic rates of land cover conversion were adjusted to conserve forested acreage not already compromised by approved subdivision activity, produced the lowest loads. The results are included in the following tables and charts for each locality.

**Table 8 Alternative Land Use Modeling Results**

| Row Labels | Acres | Nitrogen | Phosphorus | Sediment |
|---|---|---|---|---|
| **Caroline** | | | | |
| Scenario 2015 | 74,001 | 231,757 | 12,749 | 3,787,898 |
| Scenario A 2025 | 74,002 | 232,874 | 12,847 | 3,828,179 |
| Scenario B 2025 | 74,002 | 232,167 | 12,955 | 3,839,083 |
| Scenario C 2025 | 74,004 | 230,072 | 12,574 | 3,731,666 |
| Scenario D 2025 | 74,002 | 231,964 | 12,853 | 3,813,513 |
| **Spotsylvania** | | | | |
| Scenario 2015 | 61,080 | 336,098 | 31,724 | 40,783,703 |
| Scenario A 2025 | 61,080 | 349,411 | 32,394 | 41,115,038 |
| Scenario B 2025 | 61,079 | 343,590 | 32,842 | 41,898,008 |
| Scenario C 2025 | 61,081 | 340,870 | 31,903 | 40,662,860 |
| Scenario D 2025 | 61,080 | 339,875 | 32,283 | 41,320,320 |
| **Stafford** | | | | |
| Scenario 2015 | 52,384 | 274,448 | 26,094 | 30,667,858 |
| Scenario A 2025 | 52,384 | 289,969 | 24,754 | 29,762,356 |
| Scenario B 2025 | 52,384 | 281,163 | 26,825 | 31,799,105 |
| Scenario C 2025 | 52,385 | 279,452 | 23,323 | 27,834,942 |
| Scenario D 2025 | 52,384 | 278,497 | 26,556 | 31,209,744 |
| **King George** | | | | |
| Scenario 2015 | 43,015 | 155,627 | 23,203 | 3,586,083 |
| Scenario A 2025 | 43,014 | 127,050 | 14,450 | 2,650,778 |
| Scenario B 2025 | 43,014 | 156,333 | 23,122 | 3,662,798 |
| Scenario C 2025 | 43,017 | 120,351 | 13,357 | 2,414,850 |
| Scenario D 2025 | 43,015 | 155,990 | 23,164 | 3,624,822 |
| **Fredericksburg** | | | | |
| Scenario 2015 | 6,950 | 56,985 | 4,146 | 3,580,265 |
| Scenario A 2025 | 6,951 | 64,671 | 5,039 | 4,275,837 |
| Scenario B 2025 | 6,952 | 57,947 | 4,295 | 3,708,870 |
| Scenario C 2025 | 6,953 | 62,972 | 4,800 | 4,054,348 |
| Scenario D 2025 | 6,951 | 57,470 | 4,221 | 3,645,078 |

## Locality-Specific TMDL Results

### A. CAROLINE COUNTY TMDL RESULTS

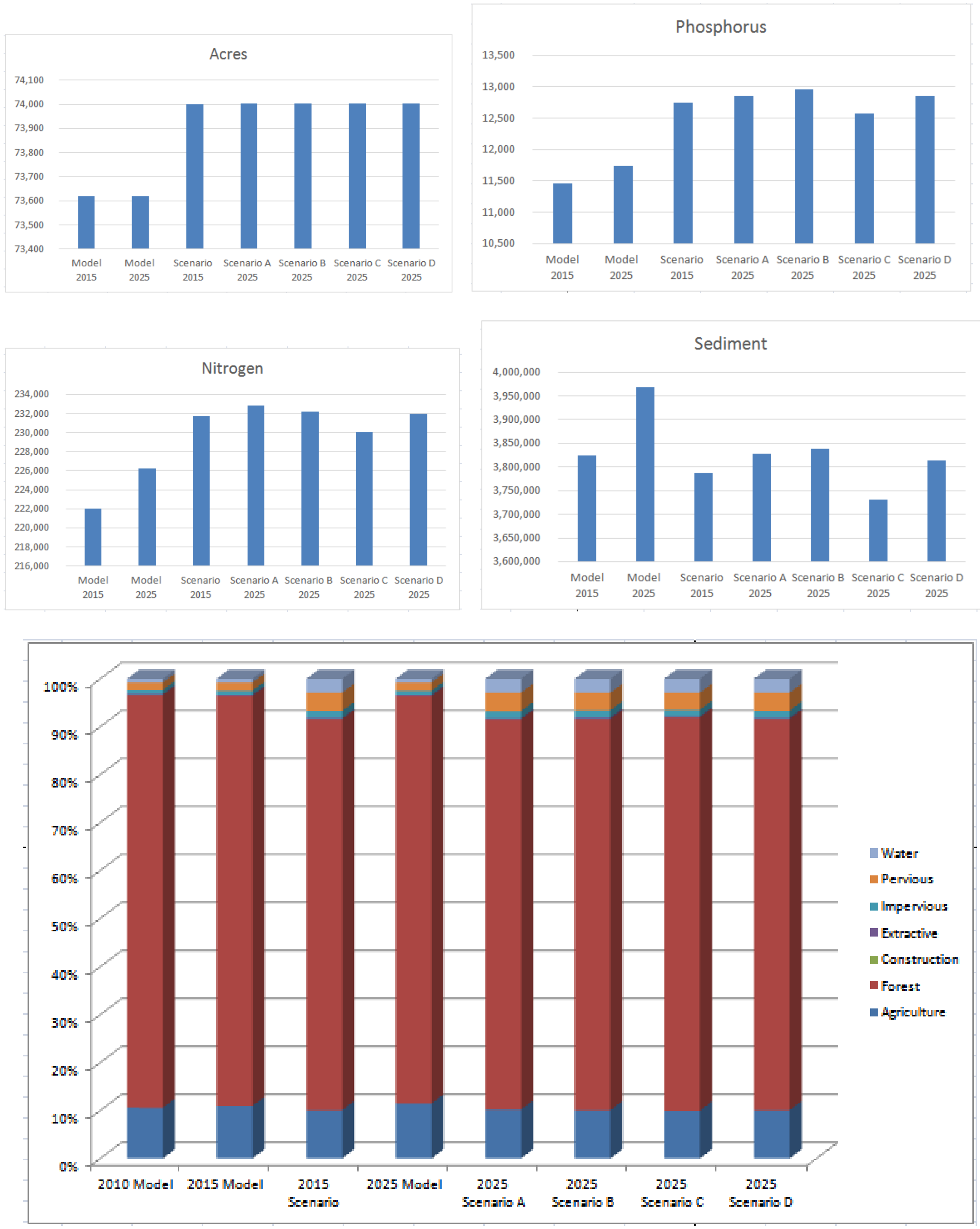
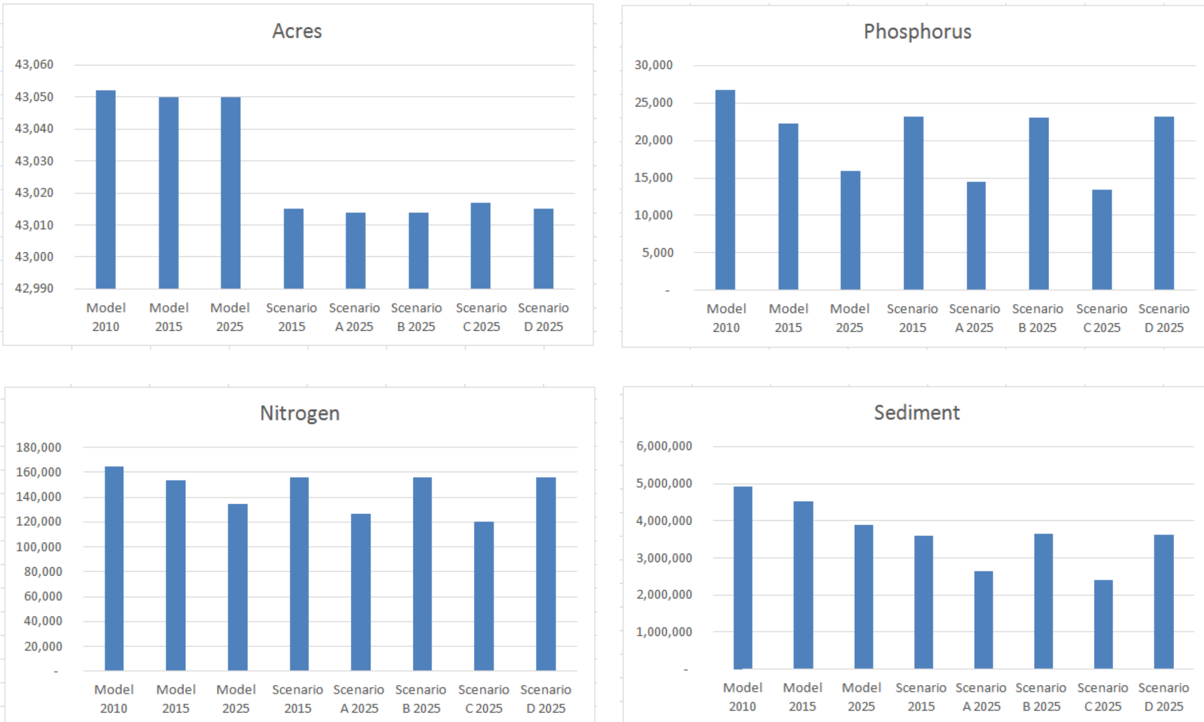



**Figure 8. Caroline County Land Cover Scenario Comparative TMDL Summary**

## B. KING GEORGE COUNTY TMDL RESULTS



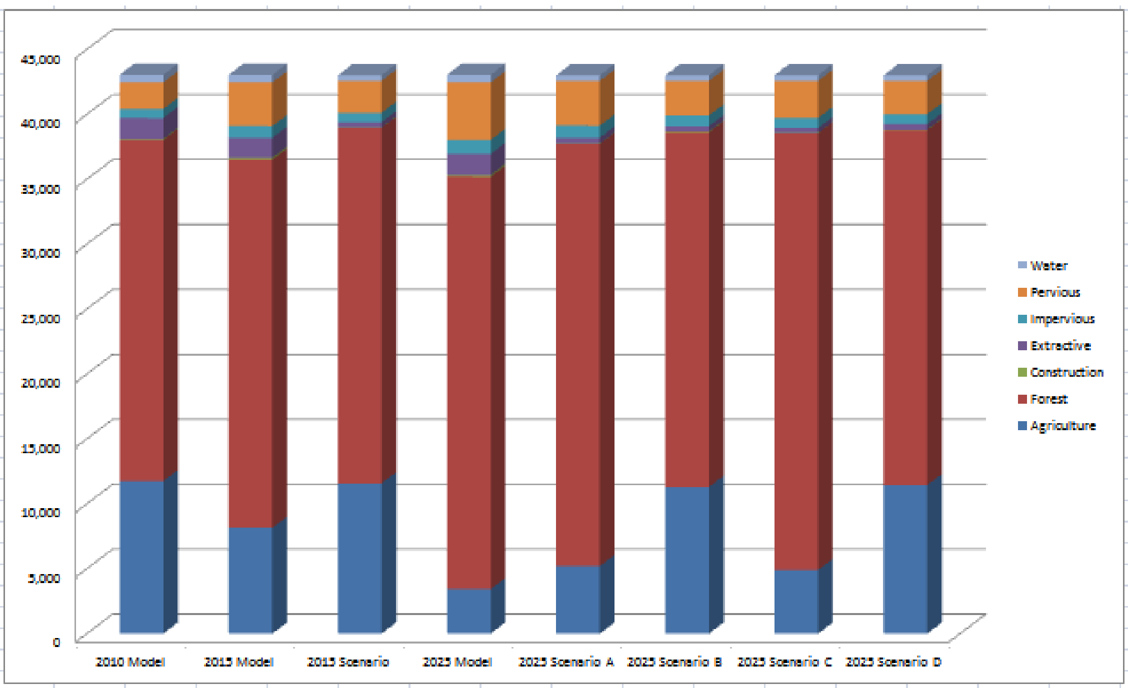




**Figure 9. King George County Land Cover Scenario Comparative TMDL Summary**

## C. SPOTSYLVANIA COUNTY TMDL RESULTS

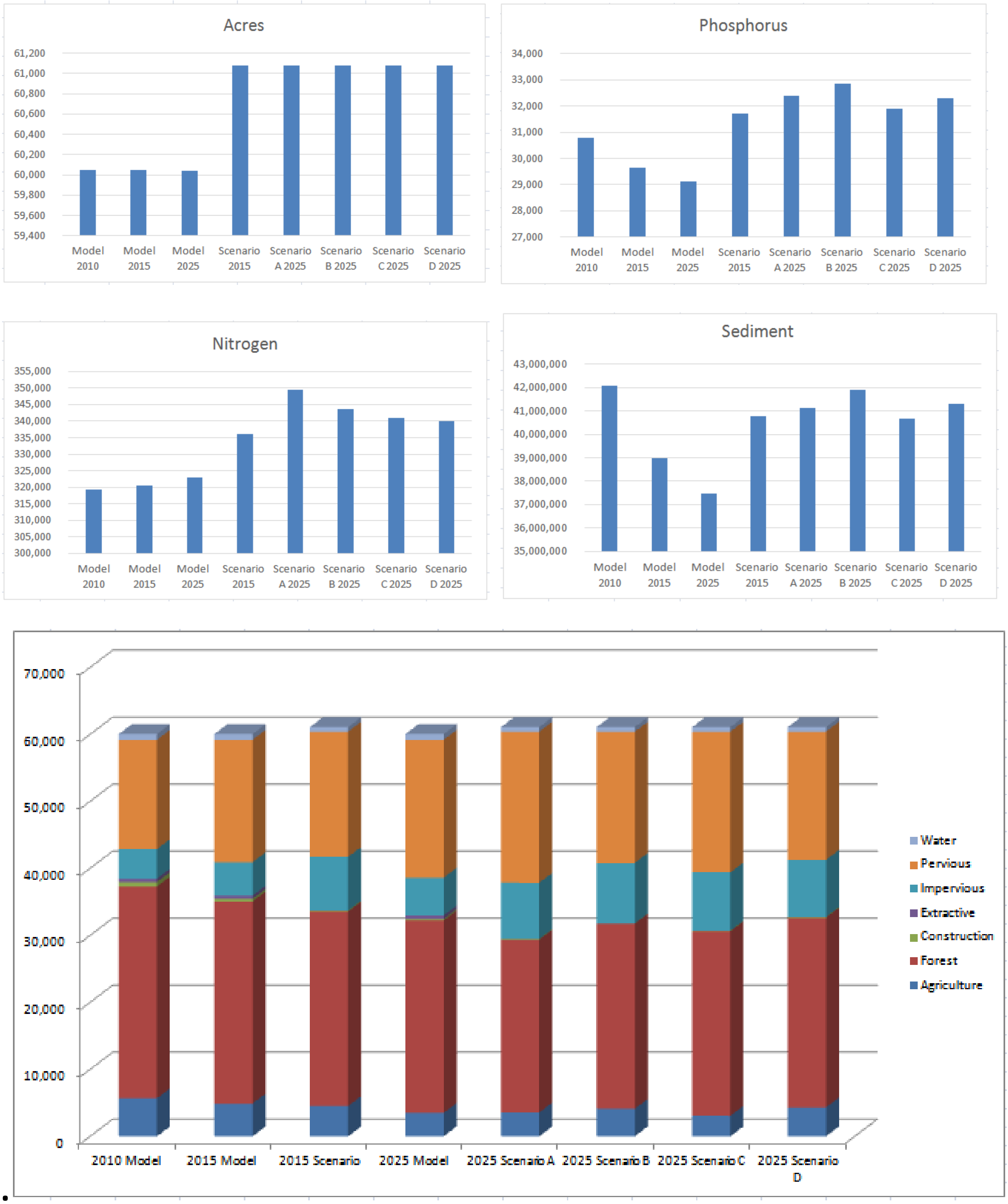
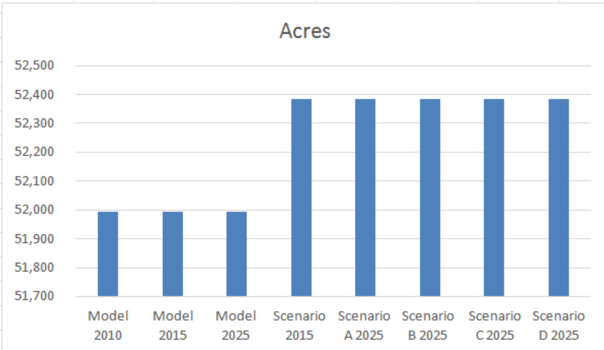
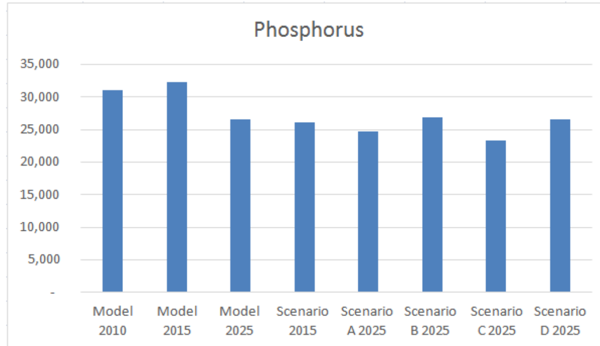
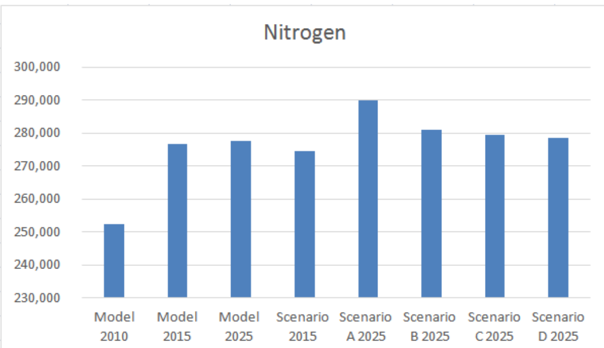


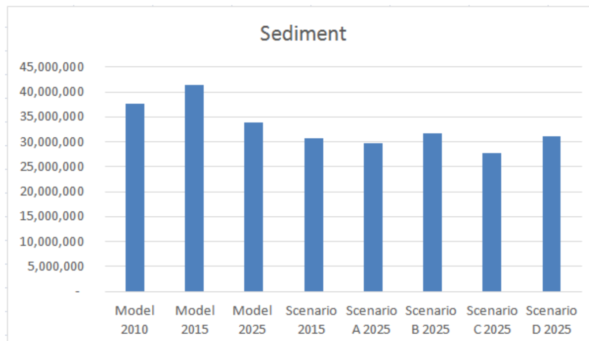

**Figure 10. Spotsylvania County Land Cover Scenario Comparative TMDL Summary**

## D. STAFFORD COUNTY TMDL RESULTS



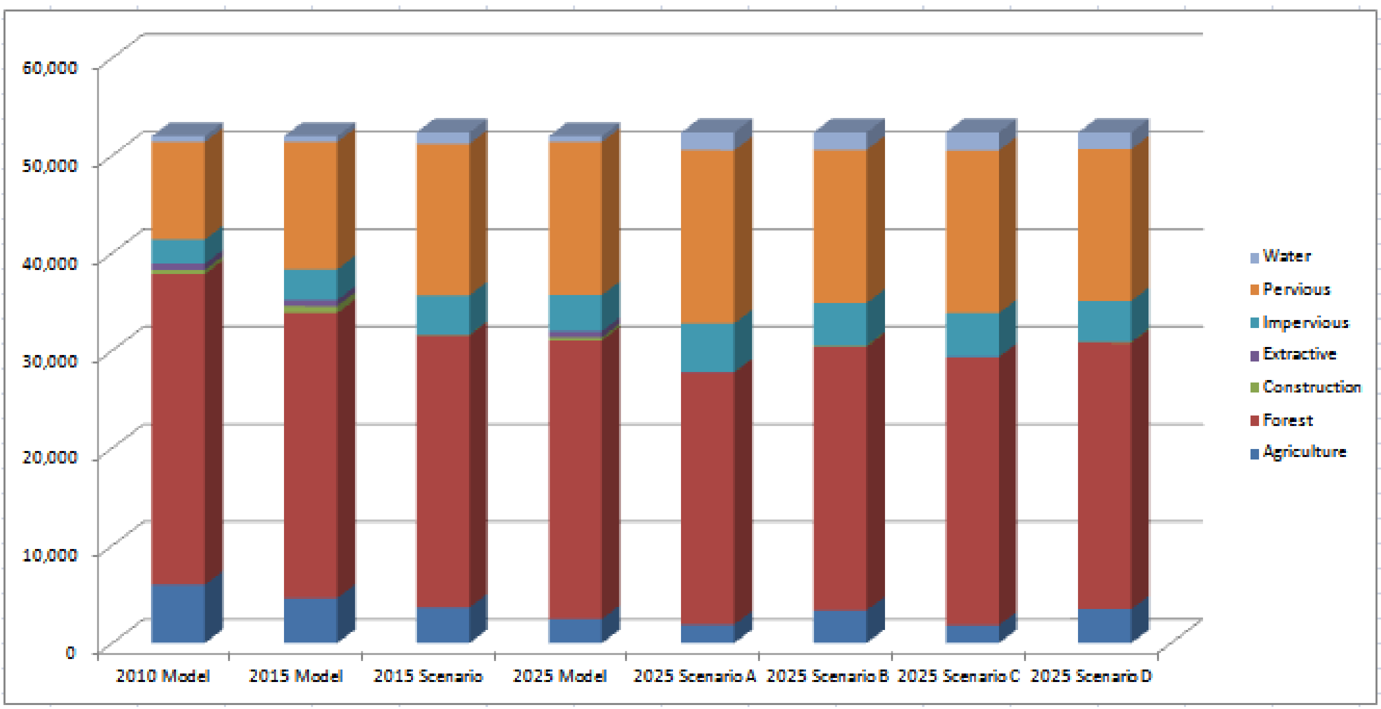
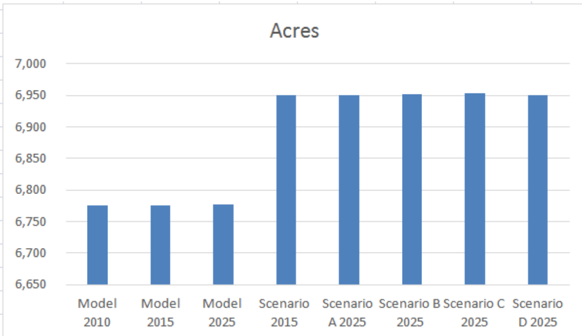
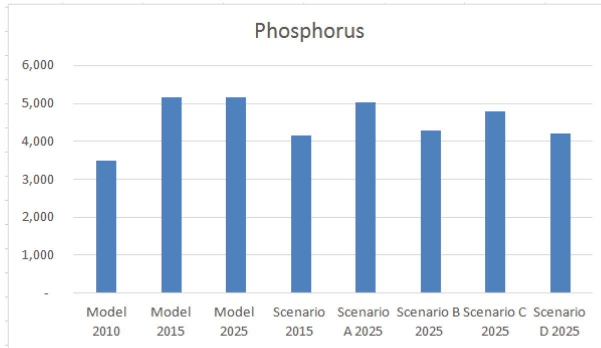
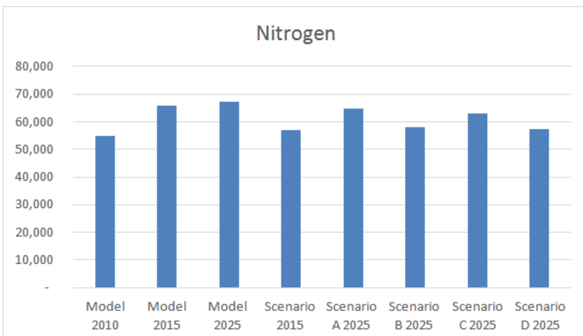



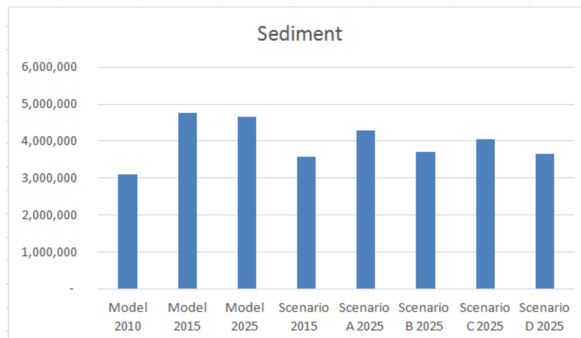

**Figure 4. Stafford County Land Cover Scenario Comparative TMDL Summary**

## E. CITY OF FREDERICKSBURG TMDL RESULTS



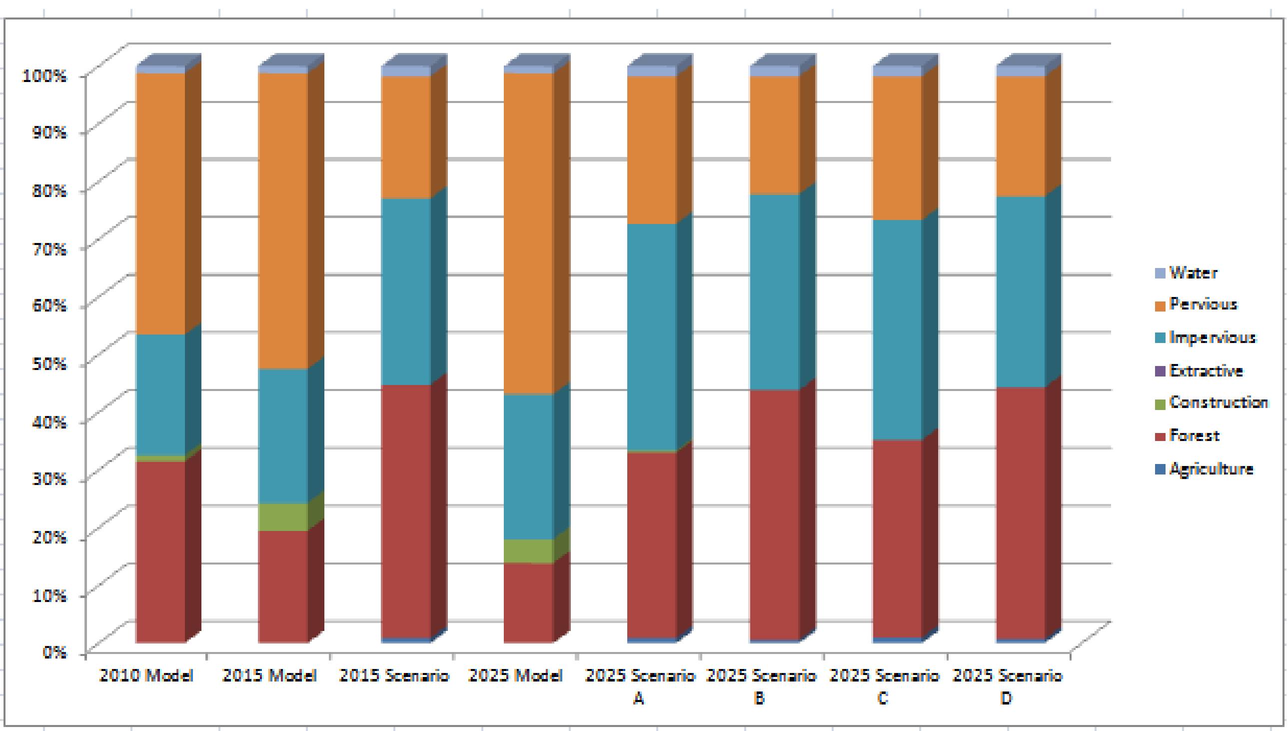




**Figure 5. City of Fredericksburg Land Cover Scenario Comparative TMDL Summary**

## Impact of Offsetting Loads Using BMPs

The results were further evaluated to estimate the load differential between the Scenario 2025 A: "Business as Usual/Decentralized Growth" and the Scenario C: "Greenprint/Forest Retention" Scenario. The result represents the load reduction that can be achieved by changing development patterns to retain more forest. Inversely, it is the load that would need to be offset through the implementation of additional BMPs if decentralized growth, with continued forest loss at historical rates of conversion to urban land covers, was allowed to continue through 2025.

**Table 9. Load Differential between Scenarios A and C**

| | Nitrogen | Phosphorus | Sediment |
|---|---|---|---|
| **Caroline** | | | |
| Scenario A 2025 | 232,874 | 12,847 | 3,828,179 |
| Scenario C 2025 | 230,072 | 12,574 | 3,731,666 |
| | **2,802** | **273** | **96,513** |
| **Spotsylvania** | | | |
| Scenario A 2025 | 349,411 | 32,394 | 41,115,038 |
| Scenario C 2025 | 340,870 | 31,903 | 40,662,860 |
| | **8,541** | **491** | **452,178** |
| **Stafford** | | | |
| Scenario A 2025 | 289,969 | 24,754 | 29,762,356 |
| Scenario C 2025 | 279,452 | 23,323 | 27,834,942 |
| | **10,516** | **1,431** | **1,927,414** |
| **King George** | | | |
| Scenario A 2025 | 127,050 | 14,450 | 2,650,778 |
| Scenario C 2025 | 120,351 | 13,357 | 2,414,850 |
| | **6,699** | **1,093** | **235,928** |
| **Fredericksburg** | | | |
| Scenario A 2025 | 64,671 | 5,039 | 4,275,837 |
| Scenario C 2025 | 62,972 | 4,800 | 4,054,348 |
| | **1,700** | **239** | **221,489** |

Table 10. BMPs Needed to Offset Loads by Locality

| BMPs Needed to Offset Loads | | |
|---|---|---|
| **Caroline** | | |
| **BMPs Needed to Offset Loads** | **Extent** | **Units** |
| Wet Ponds and Wetlands | 1140 | Acres Treated |
| Dry Extended Detention Ponds | 1140 | Acres Treated |
| Urban Stream Restoration | 5700 | Feet |
| **Spotsylvania** | | |
| **BMPs Needed to Offset Loads** | **Extent** | **Units** |
| Wet Ponds and Wetlands | 2485 | Acres Treated |
| Dry Extended Detention Ponds | 2485 | Acres Treated |
| Urban Stream Restoration | 12450 | Feet |
| **Stafford** | | |
| **BMPs Needed to Offset Loads** | **Extent** | **Units** |
| Wet Ponds and Wetlands | 2765 | Acres Treated |
| Dry Extended Detention Ponds | 2765 | Acres Treated |
| Urban Stream Restoration | 13850 | Feet |
| **King George** | | |
| **BMPs Needed to Offset Loads** | **Extent** | **Units** |
| Wet Ponds and Wetlands | 2010 | Acres Treated |
| Dry Extended Detention Ponds | 2010 | Acres Treated |
| Urban Stream Restoration | 10025 | Feet |
| **Fredericksburg** | | |
| **BMPs Needed to Offset Loads** | **Extent** | **Units** |
| Wet Ponds and Wetlands | 325 | Acres Treated |
| Dry Extended Detention Ponds | 325 | Acres Treated |
| Urban Stream Restoration | 1650 | Feet |

## Economic Value of Land Conservation BMPs in Pilot Area

BayFAST, and the BMP cost estimates in the tool, were then used to estimate the cost of implementing those additional BMPs. The exact mix of BMPs that might actually be used was impossible to forecast, so a standard mix consisting of wet ponds, extended dry detention ponds, and stream restoration was used for all localities. The BayFAST default cost values were used to estimate the costs.

Table 11. BayFAST BMP Installation Cost Estimates

| BayFAST Installation Cost Estimates | | | | |
|---|---|---|---|---|
| **BMP Full Name** | **Capital** | **Capital Unit** | **Opportunity** | **Opportunity Unit** |
| Urban Stream Restoration | 645 | $/feet | 0 | $/feet/year |
| Wet Ponds and Wetlands | 4556 | $/acres treated | 523 | $/acre treated |
| Dry Extended Detention Ponds | 4223 | $/acres treated | 1309 | $/acre treated |

BayFAST default values were also used to estimate the recurring annual operations and maintenance costs for each BMP.

Table 12. BayFAST BMP Annual O&M Cost Estimates

| BayFAST O&M Cost Estimates | | |
|---|---|---|
| **BMP Full Name** | **OandM** | **OandMUnit** |
| Urban Stream Restoration | 9 | $/feet/year |
| Wet Ponds and Wetlands | 65 | $/acre treated/year |
| Dry Extended Detention Ponds | 56 | $/acre treated/year |

The resulting cost estimates by locality to offset the additional loads if decentralized growth was allowed to continue through 2025 are summarized in the table below.

Table 13. Projected Offset Costs by Locality Under Decentralized Growth through 2025

| BMP Costs | |
|---|---|
| **Caroline** | |
| Install Costs | $ 15,773,040 |
| Annual Maintenance | $ 189,240 |
| **Spotsylvania** | |
| Install Costs | $ 34,398,585 |
| Annual Maintenance | $ 412,735 |
| **Stafford** | |
| Install Costs | $ 38,272,665 |
| Annual Maintenance | $ 459,215 |
| **King George** | |
| Install Costs | $ 27,794,235 |
| Annual Maintenance | $ 333,435 |
| **Fredericksburg** | |
| Install Costs | $ 4,512,825 |
| Annual Maintenance | $ 54,175 |

# CONCLUSION

Between now and 2025, the additional TMDL compliance costs for the Rappahannock River watershed portion of the George Washington Regional Commission localities could easily reach $125 million. One could also look at this as the cost savings the region could experience by instituting additional provisions to retain existing forestlands. These savings would be further enhanced by the increased ecosystem service value associated with those retained forests.

## Summary of Literature Review Findings on Forestland Ecosystem Services Applicable to the Project

Ecosystem services, such as provision of timber, sediment filtration, and aesthetics, are broadly defined as the benefits human populations derive, directly or indirectly, from ecosystem functions. Historically, in places such as the Chesapeake Bay Watershed, the benefits or values associated with these services have not been fully accounted for in resource decision making. Although the continued need to preserve undeveloped lands in the Bay Watershed has gained gradual recognition, emphasis by local jurisdictions and those responsible for achieving reductions in water pollution loads has focused on urban stormwater permitting, agricultural BMPs, and wastewater treatment. Consequently, less consideration both by local land-use decision makers and within the context of the TMDL modeling and accounting framework has been given to the role and value that natural landscapes have in protecting and improving water quality within the Chesapeake Bay Watershed.

The literature review conducted by the VWRRC summarizes the scientific underpinnings of ecosystem services provided by forests relative to provision of ample, clean water and the key watershed attributes to consider in prioritizing conservation efforts. In addition, the report provides discussion on valuation of forest ecosystem services. This information is provided to inform further discussions regarding local land-use decisions and programmatic efforts to incentivize conservation of private forests within the Chesapeake Bay Watershed.

The water-quality benefits, or *watershed services,* provided by forests stem from three primary processes in the form of flow management, sediment retention, and nutrient uptake. It is important to consider the specific conditions and attributes of forests that have the highest potential to provide watershed services when establishing values and payments for these services. For example, spatial location within the watershed is a critical consideration as to the degree to which a forest area will contribute to pollutant reductions. Forest soil characteristics are also a critical consideration because of the role of soil properties for controlling surface water infiltration, runoff, and nutrient and sediment retention in watersheds. In general, riparian forests located along stream corridors provide the most effective conditions for protecting water quality.

With increased interest in quantifying and valuing ecosystem services, a considerable number of modeling efforts have been developed, each with varying degrees of complexity, specificity, scale, and policy objectives. Most ecosystem service models have been developed for large landscapes and broad applications, relying on simplified simulations of watershed processes and economic dynamics. The most appropriate application of these landscape-scale models are in the context of understanding trade-offs between ecosystem service decisions and comparing relative water-quality outcomes of watershed-scale land-use-change scenarios. Once it is recognized that resources such as forests have value in terms of providing ecosystem services it is often desired to translate this information into incentives or payment for the continuation of those services.

A complete copy of the literature review conducted by the Water Resources Research Center at Virginia Tech is included in Appendix B.

## Next Steps: Suggested Tool Box Options for Consideration in Phase II

The following discussion presents opportunities to advance public policy (at federal, state and local government levels) to increase the potential for forest cover and tree canopy retention.

### A. Conservation Easement Tax Credit Policy

Through the process of placing a permanent conservation easement on their property, landowners can secure both federal and state tax credits for placing a conservation easement on their land. Conservation easements (as an instrument of forest retention) may have greater environmental (and thus greater public) benefit when located strategically. It would be logical (and preferable) if the tax credit system could take into account the differential public benefit derived through the ecosystem service functions protected or enhanced by an area under conservation easement protection. Thus, land owners that might agree to conserve the forested areas by conservation easement in areas that have been identified as being of high conservation value would realize a greater tax credit incentive than those conserving forestland in non-high conservation value areas. Localities too, could use such credits as incentives in proffer discussions with developers to encourage retention of high conservation value lands.

### B. Enforcement of Resource Protection Area Restrictions

Through the Chesapeake Bay Preservation Act (CBPA) and the regulations promulgated thereunder, local governments in the Chesapeake Bay watershed area of Virginia are required to designate and protect the natural vegetative buffers within 100 feet on either side of perennial streams and in the landward side of tidal wetlands. As described by the CPBA regulations:

> *"…these lands provide for the removal, reduction or assimilation of sediments, nutrients and potentially harmful or toxic substances in runoff entering the bay and its tributaries, and minimize the adverse effects of human activities on state waters and aquatic resources."*

In proposed rezoning of their land, some developers proffer to put RPA-designated sections of their development under a conservation easement. This raises a question as to how the annual easement stewardship monitoring responsibility will be sustained if not explicitly passed on as a responsibility of a homeowners association (HOA) established to manage the common areas and covenants associated with the development. Absent such explicit addition to the proffers accepted by local government, what is local governments' RPA monitoring and enforcement responsibility under this circumstance?

## C. Expanding Local Authority under Code of Virginia § 15.2-961.1[6]

Section 15.2-961.1 of the Code of Virginia authorizes local governments in Northern Virginia (i.e. Planning District 8) to conserve trees in the land development process as an ozone non-attainment mitigation measure. This statute as a model with possible amendments, offers several opportunities to promote tree canopy and forest retention for the improvement of the waters of the Commonwealth and the Chesapeake Bay.

1. Given the importance placed on trees and natural vegetation proximate to perennial streams and tidal wetlands and waters to be protected in defined Resource Protection Areas (RPAs), it seems reasonable that the provisions of §15.2-961.1 could be extended to local governments in other portions of the Commonwealth (e.g. the Chesapeake Bay watershed) and the justification for tree conservation under this statute, broadened from a focus on air quality non-attainment to support Chesapeake Bay water quality enhancement and TMDL goal reductions.

2. Moreover, the provisions of §15.2-961.1 allow local ordinances enacted under this statute to require tree planting where the tree conservation/preservation targets for a development cannot practically be met and further allow the local ordinance to provide for developer contributions to a local tree canopy bank or fund to allow other tree planting or conservation efforts undertaken by the locality to offset the conservation target for any development.

   In light of the potential greater efficiency of a regional tree canopy bank or fund to serve multiple local governments', enabling language added as an amendment to this section could authorize local governments to establish and operate such a regional program on its own, or allow an existing non-profit regional entity (such as Friends of the Rappahannock) or perhaps through the local regional planning district commission to do so. This might allow for more strategic tree replanting and/or tree conservation within a multi-jurisdictional sub-watershed area where larger regional environmental and landscape enhancement benefits might accrue from coordinated regional tree planting and conservation efforts in support of local government TMDL actions.

3. In the event that local or regional non-point nutrient trading credit programs become established, the potential for such entities to also support local needs for a local or regional tree canopy bank or fund might be recognized under this section.

4. § 15.2-961.1 might also reference or encourage that local ordinances adopted under this authority to encourage tree conservation and/or planting efforts which consider on-site soil conditions to promote conservation of tree canopy on more permeable A and B soils (as

[6] Conservation of tree during land development process in localities belonging to a nonattainment area for air quality standards, found at: http://law.lis.virginia.gov/vacode/title15.2/chapter9/section15.2-961.1/

classified by USDA-NCRS). Areas with these soil types are more conducive to healthy tree and plant growth. This could be one criteria for defining high conservation value forestland. Moreover, conservation of trees in areas with these highly-infiltrative soils will help retain such soils (by stabilizing the soils through the tree root systems) and promote groundwater recharge, thereby supporting the replenishment of Virginia's aquifers with storm water rather than adding flow to stormwater management surface retention structures and surface flow through the natural tributary system.

### D. 1-meter Classified Land Cover Imagery for Land Cover Change Detection

The 1-meter imagery used under the Virginia Department of Forestry's Urban Tree Canopy study program was found to provide a valuable dataset for validating and correcting land cover estimates for the City of Fredericksburg for the Chesapeake Bay TMDL model alternative growth scenarios. Now that Virginia will have 1-meter imagery available throughout first, the Chesapeake Bay watershed and eventually throughout the entire Commonwealth, building a comparable dataset for all Bay localities will lend more credibility to the Bay model and the relative non-point contributions of urban and suburban non-point pollution versus rural, non-point agricultural pollution detected from water quality sampling station throughout the Bay watershed.

Moreover, by providing quite accurate land cover data in a vector data file, it is easier to delineate specific public and private land cover inventories (and associated stormwater management responsibilities) by overlaying tax parcel boundary files, public right of way boundary files and other vector layers useful for public policy analysis. Furthermore, an accumulation of high-definition imagery over time facilitates consistent analysis change over time and enables more efficient monitoring of conservation easements, preservation of riparian buffers and other monitoring required by public policy which may be cost-prohibitively expensive through traditional on-site field inspection.

This capability applied across the Chesapeake Bay watershed could be used to build the scientific basis within the TMDL model to provide a forestland retention BMB credit to localities within the Model itself.

## Developing the Phase II Work Plan

The project team's working hypothesis was that crediting forestland retention in the TMDL will stimulate and perhaps drive development of additional incentives at the local level to conserve high conservation value forestland. Therefore, the outreach to and negotiation with local government leaders attending the Phase I Rappahannock River Basin Commission (RRBC) summit scheduled for September 23rd in Fredericksburg, Virginia will begin the focus for Phase II. The ideas and lessons learned from the Summit session will carryover when the project is expanded from its current pilot area in the George Washington Regional Commission service area of the basin to the entire Rappahannock River basin as a proxy for the Chesapeake Bay watershed.

Led by the RRBC, the project partners will work with localities, EPA and the pertinent Chesapeake Bay Program GITs to fashion the tool box of policy, regulatory and financial incentives that will stimulate land use actions that will protect currently healthy watersheds and retain high value conservation forestland. The toolbox elements have to be credible on a peer to peer basis and they have to be designed to help local officials optimize land use decisions so development can occur at the same time that water quality protection actions are maximized. The forest land TMDL best management practice credit would be the driver but only one of what could be a package of incentives available.

The Phase II planned approach is to break the Rappahannock River Basin into three separate study areas – the lower, middle and upper basins because each area will provide very different political, economic, environmental and social perspectives. The project sponsors want to learn how different dynamics change the thinking about what works and doesn't work. The lower basin is primarily rural and its near proximity to the Chesapeake Bay also makes it an area accustomed to addressing Chesapeake Bay issues. The middle basin includes some of the fastest growing urban areas in the Commonwealth and also includes large military facilities. The upper basin with its mountains represents a very different topography including headwaters and includes lands outside the Chesapeake Bay preservation area as well as federal conservation areas.

Under the sponsorship of the RRBC, a series of peer- to – peer discussion sessions will be held with geographically targeted focus groups of key elected officials and planning community senior staff to identify obstacles, incorporate best practices and lessons learned elsewhere, develop solutions, and build the tool box elements.

EPA and senior Chesapeake Bay Program GIT representatives are also urging Virginia to invite Pennsylvania to join the project in Phase II on a Commonwealth to Commonwealth basis. The rationale being that as Virginia moves forward with the implementation phase working with local government officials, Pennsylvania could serve the role as a peer reviewer and evaluate Virginia's modeling methodologies, assumptions and assortment of tools to test ways other states could adapt and implement the lessons learned in Virginia. Such partnerships could speed adoption and implementation of forestland retention actions across the Watershed as the planned 2017 amendments to the TMDL model are adopted and rolled out.

## APPENDICES

A. Detailed Supporting Technical Data:  Land Use Data Summary by Locality as Provided by Pilot Project Area Jurisdictions

B. Literature Review of Forestland Ecosystem Services for Chesapeake Bay Healthy Watersheds Forestry/TMDL (GIT-4) Pilot Project

C. Project Team Members and Personnel

## APPENDIX A: Detailed Supporting Technical Data

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **Caroline** | **74,002** | **74,002** | **74,002** | **74,002** | **74,002** |
| **RPPTF** | **74,002** | **74,002** | **74,002** | **74,002** | **74,002** |
| **A51033RL5_6070_0000** | **25,510** | **25,510** | **25,510** | **25,510** | **25,510** |
| **Agriculture** | **7,368** | **7,454** | **7,368** | **7,296** | **7,368** |
| **Forest** | **13,016** | **12,887** | **13,016** | **13,235** | **13,016** |
| **Urban Runoff** | **2,973** | **3,017** | **2,974** | **2,827** | **2,974** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 153 | 164 | 249 | 153 | 201 |
| Impervious | 626 | 634 | 626 | 591 | 626 |
| Pervious | 2,194 | 2,220 | 2,099 | 2,072 | 2,147 |
| **Water** | **2,152** | **2,152** | **2,152** | **2,152** | **2,152** |
| **F51033RL5_6070_0000** | **48,492** | **48,492** | **48,492** | **48,492** | **48,492** |
| **Agriculture** | **89** | **89** | **89** | **82** | **89** |
| **Forest** | **47,301** | **47,301** | **47,301** | **47,403** | **47,301** |
| **Urban Runoff** | **1,099** | **1,099** | **1,099** | **1,004** | **1,099** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 486 | 486 | 486 | 445 | 486 |
| Pervious | 613 | 613 | 613 | 560 | 613 |
| **Water** | **3** | **3** | **3** | **3** | **3** |
| **Caroline County Study Area** | **74,002** | **74,002** | **74,002** | **74,002** | **74,002** |
| **Agriculture** | **7,457** | **7,543** | **7,457** | **7,378** | **7,457** |
| **Forest** | **60,317** | **60,188** | **60,317** | **60,638** | **60,317** |
| **Urban Runoff** | **4,072** | **4,116** | **4,073** | **3,831** | **4,073** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 153 | 164 | 249 | 153 | 201 |
| Impervious | 1,112 | 1,120 | 1,112 | 1,036 | 1,112 |
| Pervious | 2,807 | 2,833 | 2,712 | 2,632 | 2,760 |
| **Water** | **2,155** | **2,155** | **2,155** | **2,155** | **2,155** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **King George County Study Area Total** | **43,017** | **43,015** | **43,015** | **43,015** | **43,015** |
| **RPPTF** | **43,017** | **43,015** | **43,015** | **43,015** | **43,015** |
| **A51099RL5_6070_0000** | **42,577** | **42,577** | **42,577** | **42,577** | **42,577** |
| **Agriculture** | **11,503** | **5,131** | **11,224** | **4,783** | **11,364** |
| **Forest** | **27,037** | **32,178** | **26,982** | **32,994** | **27,009** |
| **Urban Runoff** | **3,639** | **4,871** | **3,973** | **4,402** | **3,806** |
| Construction | 26 | 26 | 60 | 24 | 43 |
| Extractive | 417 | 467 | 417 | 435 | 417 |
| Impervious | 733 | 928 | 824 | 865 | 779 |
| Pervious | 2,462 | 3,450 | 2,671 | 3,216 | 2,567 |
| **Water** | **398** | **398** | **398** | **398** | **398** |
| **F51099RL5_6070_0000** | **440** | **438** | **438** | **440** | **438** |
| **Agriculture** | **74** | **74** | **74** | **30** | **74** |
| **Forest** | **334** | **333** | **333** | **379** | **333** |
| **Urban Runoff** | **0** | **0** | **0** | **0** | **0** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 0 | 0 | 0 | 0 | 0 |
| Pervious | 0 | 0 | 0 | 0 | 0 |
| **Water** | **31** | **31** | **31** | **31** | **31** |
| **King George County Study Area Total** | **43,017** | **43,015** | **43,015** | **43,015** | **43,015** |
| **Agriculture** | **11,577** | **5,205** | **11,298** | **4,813** | **11,438** |
| **Forest** | **27,371** | **32,511** | **27,315** | **33,373** | **27,342** |
| **Urban Runoff** | **3,639** | **4,871** | **3,973** | **4,402** | **3,806** |
| Construction | 26 | 26 | 60 | 24 | 43 |
| Extractive | 417 | 467 | 417 | 435 | 417 |
| Impervious | 733 | 928 | 824 | 865 | 779 |
| Pervious | 2,462 | 3,450 | 2,671 | 3,216 | 2,567 |
| **Water** | **429** | **429** | **429** | **429** | **429** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **Spotsylvania County Study Area** | **44,406** | **44,406** | **44,406** | **44,406** | **44,405** |
| **RPPTF** | 44,406 | 44,406 | 44,406 | 44,406 | 44,405 |
| **A51177RL5_6070_0000** | **32,371** | **32,371** | **32,372** | **32,371** | **32,370** |
| **Agriculture** | **2,602** | **1,884** | **2,373** | **1,824** | **2,487** |
| **Forest** | **11,647** | **10,549** | **10,799** | **11,235** | **11,223** |
| **Urban Runoff** | **17,840** | **19,655** | **18,905** | **19,030** | **18,372** |
| Construction | 131 | 78 | 39 | 76 | 85 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 5,859 | 6,465 | 6,559 | 6,260 | 6,209 |
| Pervious | 11,850 | 13,112 | 12,307 | 12,694 | 12,078 |
| **Water** | **282** | **282** | **295** | **282** | **288** |
| **A51177RU4_6040_6030** | **12,035** | **12,035** | **12,034** | **12,035** | **12,035** |
| **Agriculture** | **593** | **568** | **411** | **359** | **502** |
| **Forest** | **7,498** | **6,362** | **6,991** | **6,924** | **7,245** |
| **Urban Runoff** | **3,782** | **4,943** | **4,468** | **4,590** | **4,125** |
| Construction | 0 | 19 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 795 | 279 | 1,083 | 886 | 939 |
| Pervious | 2,987 | 4,645 | 3,385 | 3,704 | 3,186 |
| **Water** | **162** | **162** | **164** | **162** | **163** |
| **A51177RU5_6030_0001** | **12,527** | **12,527** | **12,527** | **12,527** | **12,527** |
| **Agriculture** | **608** | **395** | **608** | **376** | **608** |
| **Forest** | **7,270** | **6,272** | **7,225** | **6,567** | **7,248** |
| **Urban Runoff** | **4,485** | **5,696** | **4,527** | **5,420** | **4,506** |
| Construction | 4 | 0 | 0 | 2 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 1,237 | 1,506 | 1,267 | 1,430 | 1,254 |
| Pervious | 3,244 | 4,190 | 3,260 | 3,989 | 3,252 |
| **Water** | **164** | **164** | **167** | **164** | **165** |
| **F51177RL5_6070_0000** | **1,249** | **1,249** | **1,249** | **1,249** | **1,250** |
| **Agriculture** | **125** | **125** | **125** | **83** | **126** |
| **Forest** | **1,089** | **1,089** | **1,089** | **1,133** | **1,089** |
| **Urban Runoff** | **35** | **35** | **35** | **33** | **35** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 13 | 13 | 13 | 12 | 13 |
| Pervious | 23 | 23 | 23 | 21 | 23 |
| **Water** | **0** | **0** | **0** | **0** | **0** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **F51177RU4_6040_6030** | **2,438** | **2,438** | **2,438** | 2,438 | **2,438** |
| **Agriculture** | **489** | **489** | **489** | **353** | **489** |
| **Forest** | **1,226** | **1,226** | **1,226** | **1,363** | **1,226** |
| **Urban Runoff** | **663** | **663** | **663** | **663** | **663** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 94 | 94 | 94 | 94 | 94 |
| Pervious | 569 | 569 | 569 | 569 | 569 |
| **Water** | **59** | **59** | **59** | **59** | **59** |
| **F51177RU5_6030_0001** | **461** | **461** | **461** | 461 | **461** |
| **Agriculture** | **105** | **105** | **105** | **75** | **105** |
| **Forest** | **313** | **313** | **313** | **335** | **313** |
| **Urban Runoff** | **42** | **42** | **42** | **48** | **42** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 9 | 9 | 9 | 10 | 9 |
| Pervious | 33 | 33 | 33 | 38 | 33 |
| **Water** | **2** | **2** | **2** | **2** | **2** |
| **Spotsylvania County Study Area Total** | **61,081** | **61,080** | **61,081** | **61,080** | **61,081** |
| **Agriculture** | **4,522** | **3,566** | **4,111** | **3,070** | **4,317** |
| **Forest** | **29,043** | **25,811** | **27,643** | **27,557** | **28,344** |
| **Urban Runoff** | **26,847** | **31,034** | **28,640** | **29,784** | **27,743** |
| Construction | 135 | 97 | 39 | 78 | 85 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 8,007 | 8,366 | 9,025 | 8,692 | 8,518 |
| Pervious | 18,706 | 22,572 | 19,577 | 21,015 | 19,141 |
| **Water** | **669** | **669** | **687** | **669** | **677** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **Stafford County Study Area** | **52,159** | **52,158** | **52,159** | **52,158** | **52,159** |
| **RPPTF** | **52,159** | **52,158** | **52,159** | **52,158** | **52,159** |
| **A51179RL5_6070_0000** | **27,486** | **27,486** | **27,486** | **27,486** | **27,486** |
| **Agriculture** | **2,782** | **1,450** | **2,535** | **1,401** | **2,782** |
| **Forest** | **9,818** | **9,545** | **9,666** | **10,146** | **9,818** |
| **Urban Runoff** | **14,763** | **16,368** | **15,127** | **15,816** | **14,763** |
| Construction | 61 | 21 | 74 | 21 | 61 |
| Extractive | 30 | 31 | 30 | 29 | 30 |
| Impervious | 3,093 | 3,403 | 3,172 | 3,288 | 3,093 |
| Pervious | 11,579 | 12,913 | 11,851 | 12,477 | 11,579 |
| **Water** | **123** | **123** | **158** | **123** | **123** |
| **A51179RU4_5640_6030** | **13,157** | **13,157** | **13,157** | **13,157** | **13,158** |
| **Agriculture** | **358** | **187** | **343** | **172** | **354** |
| **Forest** | **11,616** | **11,345** | **11,588** | **11,480** | **11610** |
| **Urban Runoff** | **1,053** | **1,495** | **1,096** | **1,376** | **1,064** |
| Construction | 0 | 0 | 0 | **0** | 0 |
| Extractive | 0 | 0 | 0 | **0** | 0 |
| Impervious | 286 | 366 | 302 | **336** | 289 |
| Pervious | 767 | 1,130 | 794 | **1,039** | 775 |
| **Water** | **130** | **130** | **130** | **130** | **130** |
| **A51179RU5_6030_0001** | **11,433** | **11,433** | **11,434** | **11,433** | **11,433** |
| **Agriculture** | **472** | **231** | **430** | **215** | **438** |
| **Forest** | **6,807** | **5,657** | **6,112** | **5,795** | **6,278** |
| **Urban Runoff** | **4,063** | **4,835** | **4,182** | **4,713** | **4,007** |
| Construction | 0 | 0 | 53 | 0 | 26 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 893 | 1,080 | 1,089 | 1,006 | 963 |
| Pervious | 3,170 | 3,980 | 3,040 | 3,706 | 3,018 |
| **Water** | **91** | **710** | **710** | **710** | **710** |
| **F51179RL5_6070_0000** | **82** | **82** | **82** | **82** | **82** |
| **Agriculture** | **32** | **32** | **32** | **18** | **32** |
| **Forest** | **37** | **37** | **37** | **50** | **37** |
| **Urban Runoff** | **13** | **13** | **13** | **14** | **13** |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 4 | 4 | 4 | 4 | 4 |
| Pervious | 9 | 9 | 9 | 10 | 9 |
| **Water** | **0** | **0** | **0** | **0** | **0** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **Stafford Co. Study Area Total** | **52,158** | **52,158** | **52,159** | **52,158** | **52,159** |
| **Agriculture** | **3,644** | **1,900** | **3,340** | **1,806** | **3,606** |
| **Forest** | **28,278** | **26,584** | **27,403** | **27,471** | **27,743** |
| **Urban Runoff** | **19,892** | **22,711** | **20,418** | **21,919** | **19,847** |
| Construction | 61 | 21 | 127 | 21 | 87 |
| Extractive | 30 | 31 | 30 | 29 | 30 |
| Impervious | 4,276 | 4,853 | 4,567 | 4,634 | 4,349 |
| Pervious | 15,525 | 18,032 | 15,694 | 17,232 | 15,381 |
| **Water** | **344** | **963** | **998** | **963** | **963** |

| Locality, Landriversegment & Land Cover Estimates | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **City of Fredericksburg Study Area** | **6,952** | **6,952** | **6,952** | **6,952** | **6,952** |
| **RPPTF** | 6,952 | 6,952 | 6,952 | 6,952 | 6,952 |
| **A51630RL5_6070_0000** | **6,417** | **6,417** | **6,417** | **6,417** | **6,417** |
| **Agriculture** | 61 | 61 | 38 | 67 | 50 |
| **Forest** | 2,669 | 1,888 | 2,627 | 2,033 | 2,648 |
| **Urban Runoff** | 3,571 | 4,353 | 3,635 | 4,202 | 3,603 |
| Construction | 0 | 0 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 2,208 | 2,691 | 2,319 | 2,632 | 2,264 |
| Pervious | 1,363 | 1,662 | 1,315 | 1,627 | 1,339 |
| **Water** | 115 | 115 | 116 | 115 | 116 |
| **A51630RU5_6030_0001** | **368** | **368** | **368** | **368** | **368** |
| **Agriculture** | 0 | 0 | 0 | 0 | 0 |
| **Forest** | 253 | 219 | 253 | 236 | 253 |
| **Urban Runoff** | 107 | 141 | 107 | 124 | 107 |
| Construction | 0 | 22 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 33 | 38 | 36 | 39 | 34 |
| Pervious | 74 | 82 | 71 | 86 | 73 |
| **Water** | 8 | 8 | 8 | 8 | 8 |

| Locality, Landriversegment & Land Cover | 2015 Estimate | 2025 Scenario A | 2025 Scenario B | 2025 Scenario C | 2025 Scenario D |
|---|---|---|---|---|---|
| **F51630RL5_6070_0000** | **167** | **167** | **167** | **167** | **167** |
| **Agriculture** | **0.0** | **0** | **0** | **0** | **0** |
| **Forest** | **129.3** | **129** | **129** | **129** | **129** |
| **Urban Runoff** | **37.6** | **38** | **38** | **38** | **38** |
| Construction | 0.0 | 0 | 0 | 0 | 0 |
| Extractive | 0.0 | 0 | 0 | 0 | 0 |
| Impervious | 4.5 | 4 | 4 | 4 | 4 |
| Pervious | 33.1 | 33 | 33 | 33 | 33 |
| **Water** | **0.0** | **0** | **0** | **0** | **0** |
| **Fredericksburg City Total** | **6,785** | **6,952** | **6,952** | **6,952** | **6,952** |
| **Agriculture** | **61** | **61** | **38** | **67** | **50** |
| **Forest** | **2,922** | **2,236** | **3,010** | **2,398** | **3,030** |
| **Urban Runoff** | **3,678** | **4,532** | **3,779** | **4,363** | **3,748** |
| Construction | 0 | 22 | 0 | 0 | 0 |
| Extractive | 0 | 0 | 0 | 0 | 0 |
| Impervious | 2,241 | 2,733 | 2,359 | 2,676 | 2,302 |
| Pervious | 1,437 | 1,777 | 1,420 | 1,746 | 1,445 |
| **Water** | **123** | **123** | **125** | **123** | **124** |
| | | | | | |
| **PD 16 Study Area Total** | **237,042** | **237,208** | **237,209** | **237,209** | **237,209** |
| **Agriculture** | **27,261** | **18,275** | **26,244** | **17,134** | **26,868** |
| **Forest** | **147,931** | **147,330** | **145,688** | **151,437** | **146,776** |
| **Urban Runoff** | **58,128** | **67,264** | **60,883** | **64,299** | **59,217** |
| Construction | 222 | 166 | 226 | 123 | 215 |
| Extractive | 600 | 662 | 696 | 617 | 648 |
| Impervious | 16,369 | 18,000 | 17,887 | 17,903 | 17,060 |
| Pervious | 40,937 | 48,664 | 42,074 | 45,841 | 41,294 |
| **Water** | **3,720** | **4,339** | **4,394** | **4,339** | **4,348** |

# APPENDIX B: Literature Review of Forestland Ecosystem Services for Chesapeake Bay Healthy Watersheds Forestry/TMDL (GIT-4) Pilot Project

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**14 September 2015**

# Literature Review of Forestland Ecosystem Services for Chesapeake Bay Healthy Watersheds Forestry/TMDL (GIT-4) Pilot Project

## A. Introduction

Ecosystem services, such as provision of timber, sediment filtration, and aesthetics, are broadly defined as the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997). Historically, in places such as the Chesapeake Bay Watershed (CBW), the benefits or values associated with these services have not been fully accounted for in resource decision making. As a result, the Chesapeake Bay has experienced significant resource degradation and scarcity (Chesapeake Bay Commission 1987).

Initiation of the Chesapeake Bay Program in the early 1980s marked formal recognition of degraded resource conditions within the Bay. Resulting agreements and restoration plans have begun to recognize the value of the CBW's ecosystem services and importance in achieving desired ecological, economic, and cultural conditions. As evidence, conservation of undeveloped landscapes has been a priority strategy throughout the history of the Bay Program (Chesapeake Bay Commission 2013).

In response to continued degradation of water quality, the U.S. Environmental Protection Agency (EPA), under Presidential Executive Order, established a Total Maximum Daily Load (TMDL) in 2010, which set and assigned specific pollutant-load reduction targets for sediment and nutrients to the Bay (EPA 2010). With establishment of a structured TMDL implementation plan, some concern has been expressed regarding potential over-emphasis on a smaller suite of remediation practices (Blankenship 2011). Although the Executive Order does call for the continued need to preserve undeveloped lands in the Bay Watershed, emphasis by local jurisdictions and those responsible for achieving reductions has focused on urban stormwater permitting, agricultural best management practices (BMPs), and wastewater treatment infrastructure (Gilbert, et al. 2012). As a result, less consideration both by local land-use decision makers and within the context of the TMDL modeling and accounting framework, has been given to the role and value that natural landscapes have in protecting and improving water quality within the CBW (Gilbert et al 2012, STAC 2012, Chesapeake Bay Program 2015a).

In 2012, at the request of the *Maintain Healthy Watersheds Goal Implementation Team* (GIT4 team), the Bay Program's Science and Technical Advisory Committee (STAC) convened a workshop to discuss whether sufficient scientific information existed to support adjusting the Bay TMDL model nutrient and sediment processing rates assigned to natural landscapes. Workshop participants came to a consensus that a "sufficient scientific basis exists" and recommended several modifications to the Watershed Model as part of the 2017 Midpoint

Assessment, including new land use classifications and loading rates for such land classes (STAC 2012).

Of particular interest in the STAC discussions was the role of forests in reducing pollutant loads and therefore enhancing water quality. The Chesapeake Bay Program Healthy Watersheds Goal Implementation Team funded the current Healthy Watersheds Forest/TMDL project in Virginia to test and assess the water quality management role of forests and determine the economic value of that ecosystem service benefit within the context of the Chesapeake Bay TMDL. Specifically, the pilot study sponsored by the Virginia Departments of Forestry and Environmental Quality, The Nature Conservancy, the Chesapeake Bay Commission, the Rappahannock River Basin Commission, the George Washington Regional Commission and the Virginia Water Resources Center at Virginia Tech examines whether effects of private forest conservation and new public policy action, along with requiring urban BMPs on all new development, result in sufficient forecasted pollutant load reductions to meet required targets. An intended outcome is to explore the potential of forestland conservation as a cost-effective "green" infrastructure alternative for local governments to consider in-lieu of more traditional and costly "grey" infrastructure projects. In doing so, the implementation team desires to bridge the gap between historical objectives of land conservation and the more structured water quality goals of the Bay TMDL.

In support of the modeling efforts of the *Healthy Watersheds Forest Retention Project*, this report is intended to provide the scientific underpinnings of ecosystem services provided by forests and the key watershed attributes to consider in prioritizing conservation efforts. In addition, the report provides discussion on valuation of forest ecosystem services. This information is provided to inform further discussions regarding local land-use decisions and programmatic efforts to incentivize conservation of private forests within the CBW.

## B. Attributes and Services

The water-quality benefits, or *watershed services,* provided by forests stem from three primary processes in the form of flow management, sediment retention, and nutrient uptake (Todd 1993). Professional publications, particularly those focused on payment for ecosystem service (PES) schemes often cite these watershed services provided by forests in general terms, without details of specific, necessary conditions (Hanson et al. 2011, Barnes et al. 2010, Majanen et al. 2011). Although the academic literature has demonstrated these processes in various locations, the universality of their application has also been questioned (Neary, et al. 2009, Johnson et al. 2012, Calder 2002, Lele 2009). Therefore in the context of establishing values and payments for service, it is important to consider the specific conditions and attributes of forests that have the highest potential to provide watershed services.

Spatial location within the watershed is a critical consideration as to the degree to which a forest area will contribute to pollutant reductions. Riparian forests have been noted to have the most potential for nutrient and sediment filtration relative to upland forests (Lele 2009). However, because a forest is in a riparian location does not mean it will abate nutrient and sediment loading to nearby watercourses (Johnson et al. 2012). Although upland forests may occur in close proximity to stream channels in headwater streams, they also tend to have higher gradients and erosion potential (Norton and Fisher 2000). Forests located along higher-order streams with low gradients tend to have the greatest potential for erosion control and sediment retention given slow flow regimes and potential for groundwater absorption (Anbumozhi et al. 2005). Furthermore, many studies have examined forests in relation to their impacts on water quality at relatively small spatial scales. Although some inferences have been made regarding the location of forests in a watershed with respect to impacts on watercourses, it is recognized that knowledge gaps remain concerning the role of forests in determining the extent of connective hydrological and biogeochemical processes in larger river basins (Lorz et al. 2007).

Forest soils are a critical component for infiltration and sediment retention in watersheds containing forest cover. In a study of two coastal watersheds within the CBW, it was noted that soil characteristics can completely over-ride landcover effects (Norton and Fischer 2000). Forest soils are important in both their ability to influence surface flows or runoff, and their ability to filter sediment and nutrients (Todd 1993). In several studies, well-drained forest soils, typically those characterized by sandy texture, tend to have greater potential for facilitating nitrogen uptake from rapid infiltration and subsurface flows and from retention of phosphorus through minimization of surface flows (Weller et al. 1994, Norton and Fischer 2000). In addition, those forests that have more hydric soil conditions were found to have greater potential for denitrification (Johnson et al. 2012). As with other variables, the potential contributions of forest soils are highly dependent on their interactions with other ecological, hydrologic, and geomorphic conditions (Weller et al. 1994).

Nitrogen transport from agricultural lands tends to occur via groundwater and therefore the potential for forests to uptake these nutrients will depend on soil properties and the groundwater depth underlying forested areas. Under base-flow conditions, groundwater with shallow water tables tends to hold more potential for nitrogen uptake than deeper groundwater, where flows may bypass root zones in riparian areas and discharge directly to the streambed with minimal plant uptake (Reilly et al. 1994). The depth of groundwater can fluctuate over time and is highly dependent upon interactions with other factors such as soil texture and depth, geology, topography, and vegetation.

A significant number of studies have examined watersheds specifically within the Chesapeake Bay region. Lowrance et al. (1997) provide a comprehensive review of these studies, specifically reviewing the function of riparian forests across the various Physiographic regions of the CBW (Figure 13). Although the meta-analysis of Lowrance et al. (1997) was concerned specifically with forested riparian buffers, it is very relevant to this report, as other literature points to riparian forests as having the greatest potential among land uses for nutrient and sediment reductions (Anbumozhi et al. 2005, Corbett et al. 1997, Hively et al. 2011). Lawrance et al. (1997) also make several general conclusions regarding characteristics of forests that provide the greatest potential for providing watershed services. With respect to sediment retention, natural riparian forests are particularly effective in filtering fine sediments with the main limiting factors being slope and flow concentration. As with other studies, the meta-analysis found that nitrate removal was most effective in shallow groundwater settings, where water moves in short, shallow flow paths and is accessible for maximum root uptake. Conversely, nitrogen removal was found to be less effective in areas where groundwater is deeper and more regionalized. Control of dissolved phosphorus was found to be the least generalizable function of riparian forests and was closely linked to filtration of fine sediments. The authors note that riparian forests appear to have very low net dissolved phosphorus retention, but may have increased effectiveness when coupled with vegetation that has greater potential for phosphorus uptake In addition to generalized conclusions, the Lowrance et al. (1997) meta-analysis offers summarized characteristics of the various Physiographic regions of the CBW (Figure 13).

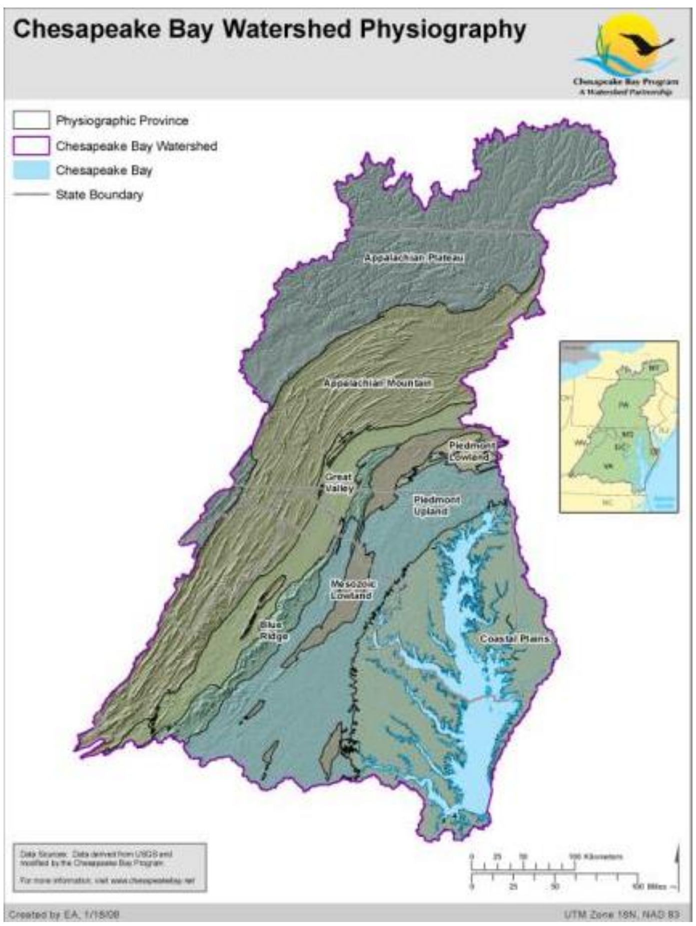


Figure 13. Chesapeake Bay Watershed Physiography
Source: http://www.chesapeakebay.net/images/maps/cbp_19637.pdf

For nitrogen removal from groundwater, the Inner Coastal Plain region of the Atlantic Coastal Plan Province and Piedmont regions characterized by thin soils and shales have the greatest potential. For the Piedmont region, it was noted that much of the potential will be determined by topography of the valleys, which will control connectivity of nitrogen sources to riparian forests and surface water courses. Those regions with high infiltration, such as well-drained uplands in the Outer Coastal Plain and those with deep groundwater or connections to regional aquifers, such as the Valley and Ridge have the lowest potential for groundwater nitrogen removal. All regions were determined to have a medium-to-high expected level of sediment removal. However, it was noted that the extent of sediment removal was dependent upon the concentration of sediment in the flow and degree of slope. All regions were also determined to have medium-to-low expected levels for removing dissolved phosphorus. Most phosphorus removal was associated with surface sediment retention rather than uptake by tree root systems, which may have limited capacity for additional phosphorus absorption.

As with previously cited research, Lowrance et al. (1997) noted that watershed systems are highly dynamic, making generalization across Physiographic regions difficult. The authors remarked that upstream activities that may alter hydrologic or pollutant dynamics will alter effectiveness of riparian forests in their ability to control nutrients and sediment. Lowrance et al. (1997) stated that those riparian forests closest to or mimicking natural states will increase long-term effectiveness in terms of protecting water quality. The extent to which disturbances such as timber harvesting and road development can be minimized and land conservation can be maximized will ensure that watershed services are sustained in the long term.

## C. Valuing Forest Watershed Services

Ecosystem goods (e.g., provision of timber) and services (e.g., waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997). Ecosystem goods have been valued throughout history, typically in the form of commodities or other tangible production inputs. Ecosystem *services,* which are often less tangible, have only recently been recognized as having economic value within the context of natural resource decision making (Daily et al. 2009, Millennium Assessment 2005). Although it is often desired to formulate a single economic value for a particular service, valuation is not as straightforward as traditional (commodity) goods and is an evolving branch of science that includes contributions from multiple social and natural science fields (Farber et al. 2006).

In establishing value for ecosystem services, it is important to identify the *type* or classification of service provided. A general consensus has been accepted that services can be grouped into three broad categories: 1) provisioning, 2) regulating, or 3) cultural (Table 1). Unfortunately, less consensus has been reached as to which category services derived from forests for water quality or watershed services should be categorized (Ojea et al. 2012). Although forests provide regulation of sediment and nutrient flow, they have also been considered to provide (provisioning service) clean water (Millennium Assessment 2005). The need for making this distinction is that in calculating total economic values there exists the potential for double counting (Boyd and Banzhaf 2007).

**Table 14. Ecosystem Service Categories and Examples.[1]**

| **Provisioning** | **Regulating** | **Cultural** |
|---|---|---|
| *Products obtained from ecosystems* | *Benefits obtained from regulation of ecosystem processes* | *Nonmaterial benefits obtained from ecosystems* |
| • Fruits and Vegetables<br>• Fresh water<br>• Fiber<br>• Fuelwood | • Climate<br>• Water Quality<br>• Pollination | • Recreation<br>• Aesthetics<br>• Sense of place<br>• Cultural, religious, historical significance |
| **Supporting Services**<br>*Services necessary for the production of all other ecosystem services* | | |
| • Soil formation | • Nutrient cycling | • Primary production |

[1]Millennium Assessment Chapter 2 (2005).

In determining values it is also important to make a clear distinction of what is being valued. With respect to forests and water quality or what is often termed "watershed services" this can be challenging, as there is not always a clear distinction between the structure of the ecosystem, the relevant ecosystem process, and the impact that the ecosystem produces (Ojea et al. 2012). For example, land classification is often used as a proxy for watershed condition, with more forestland representing a desired structure. However, it is the filtration properties of forest soils that are the provisioning element, but the impact or outcome is the level of water quality. As Ojea et al. (2012) explain the focus should be on the outcome, not the process for the purposes of valuation, as this is what has economic value.

Various methods have been developed for determining the value of non-market goods and services. These methods can be broadly categorized as 1) revealed willingness to pay, 2) expressed willingness to pay, 3) cost analysis, and 4) benefit transfer (Table 15).

**Table 15. Valuation Methodologies.[1]**

| Category | Method | Description |
|---|---|---|
| Revealed Willingness to Pay | Hedonic Pricing | Determining the value of a commodity's characteristics both internal and external based on actual market prices. |
| | Travel Cost | A location's value based on the time and expenditures spent by individuals to arrive at the location. |
| Expressed Willingness to Pay | Contingent Valuation | Survey-based valuation in which individuals directly express how much they would be willing to pay for a good or service. |
| | Contingent Choice | Survey-based valuation in which individuals are asked to choose among several options from which willingness to pay is inferred. |
| Cost Analysis | Cost Avoidance | The total cost necessary to avoid an impact. May also be calculated as the total cost of the impact if it were to occur. |
| | Replacement Cost | The cost to replace the benefit or service of study. Often called the mitigation cost. |
| | Substitute Cost | The cost or value of an alternative choice, which provides the same level of service or benefit. |
| Benefit Transfer | | Estimate value by transferring available information from existing studies to subject location or context. |

1. Farber et al. (2006).

In the context of examining forest conservation as an alternative strategy to reduce pollutant loads delivered to the CBW, cost-analysis methodology may be the most relevant, particularly the substitute-cost method. Advantages to cost-analysis methods are that it is often easier to determine the costs of producing benefits rather than measuring the value of the benefit itself. Disadvantages of this methodology are that it does not provide information regarding social preferences and may not necessarily represent the full value of the resource (Farber et al. 2006). However, in the context of our ongoing *Healthy Watersheds Forest Retention Project* these are of less concern because a primary objective is to demonstrate the benefits and cost-effectiveness of forest conservation compared with more infrastructure-intensive alternatives to pollutant reduction.

Recognition of watershed services and use of forest conservation as a strategy to protect water has gained significant interest (Bertule et al. 2014, Gartner et al. 2013, Firehock and Kline 2013, Burke and Dunn 2010). In these studies, natural landscapes are often referred to as *green infrastructure* and the substitution-valuation analysis as a *green vs. grey* cost analysis. Such studies aim to demonstrate the cost savings associated with preserving existing landscapes rather than constructing additional infrastructure such as stormwater systems and water-filtration facilities. The most famous of these case studies is New York State, which in the early 1990s established a significant forest and riparian conservation program to which the Department of Environmental Protection (DEP) has committed $1.5 billion to protect source water for the City of New York. Although these costs are significant, the DEP has estimated that its efforts have avoided $10 billion in filtration plants and other hard infrastructure costs (NYEP 2010). Since the implementation of this program other cities have followed suite with similar analyses of green vs. grey infrastructure costs (Table 16).

**Table 16. Grey vs. Green Costs Savings for Water Quality ($ millions).**

| Community | Grey Infrastructure Costs | Green Infrastructure Costs | Estimated Savings |
|---|---|---|---|
| Lancaster, PA[1] | $120 | $94.5 | $25.5 |
| Fort Collins and Greeley, CO[2] | $25 | $9.6 | $15.4 |
| Tualatin River, OR[3] | $60-150 | $4.6 | $50.4 - $145.4 |
| Philadelphia, PA[3] | $25.4 – $58.4 | $19.4 - $44.5 | $6 - $14 |
| Montgomery County, MD[4] | - | - | $55.5 - $240.4 |
| Washington D.C.[4] | - | - | $7.7 - $26.7 |
| Prince George’s County, MD[4] | - | - | $.019-.255 |
| Milwaukee, WI[5] | - | - | $2.8 - $8.5 |
| Ann Arbor, MI[5] | - | - | $53.2 - $184.6 |

[1]Mittman and Kloss (2014), [2]Talberth et al. (2013), [3]Bertule et al. (2014), [4]Buckley et al. (2011a), [5]Buckley et al. (2011b).

Although the above-cited studies are attractive for their ability to produce a tangible value, they should be reviewed with significant caution. Cost-valuation studies often generalize the potential pollutant reductions or services, such as assuming uniform conditions across an entire watershed (Farber et al 2006). As discussed in previous sections, spatial location and connectivity to other elements of a watershed are important factors in understanding the service potential of a watershed. In addition, as watersheds are highly dynamic systems, structural changes such as precipitation rates and groundwater levels vary over time making the flow of benefits highly variable (Lele 2009). By assuming a constant flow of benefits in order to determine a net present value, a valuation can significantly misrepresent the quantity of service within a watershed.

### D. Models to Quantify and Value Ecosystem Services

With increased interest in quantifying and valuing ecosystem services a considerable number of modeling efforts have been developed, each with varying degrees of complexity, specificity, scale, and policy objectives (Bagstad et al. 2013a, Volk 2013). Several ecosystem service models including *Invest*, maintained by the Natural Capital Project[7], and *ARIES*, developed by a consortium of academic[8] institutions are intended for large landscape application and publicly available for use. In order to allow for broad application, such models tend to rely on simplified natural systems modules that do not account for dynamic processes or dynamic interrelationships (Volk 2013). The most appropriate application of these landscape-scale models are in the context of understanding trade-offs between ecosystem service decisions and understanding watershed-scale land-use change scenarios (Vigerstol and Aukema 2011).

Development of markets or Payment for Environmental Services (PES) schemes that commoditize ecosystem services requires robust measurement of the stock and flow of services (Crossman et al. 2013). More traditional hydrologic models, such as the Soil and Water Assessment Tool (SWAT) developed by the USDA and the Variable Infiltration Capacity (VIC) model were developed to examine more specific hydrologic functions, such as flow management and BMP effectiveness in reducing nutrient loads. The challenge with such models, however, is integration with economic models to understand complex coupled human and natural systems (Burkhard et al. 2013). Given increased interest in such studies, efforts such as the Multiscale Integrated Model of Ecosystem Services (MIMES) have been developed (Boumans et al. 2015). Such models are more robust and able to capture ecosystem service flows over time, but require a considerable amount of resources and expertise.

The field of ecosystem service quantification and valuation is still fairly new. With time and continued interest, additional research will become available to calibrate large landscape models to incorporate higher sensitivities of more complex ecological processes (Sanchez-Canales et al. 2015, Hamel et al. 2015, Bagstad et al. 2013a). Similarly complex coupled systems such as MIMES will continue to develop and allow for broader applications (Boumans

[7] Natural Capital Project is a partnership between Stanford University, University of Minnesota, the Nature Conservancy and World Wildlife Federation.
[8] ARIES is a collaboration of UNEP, WCMC, University of Vermont, Conservation International, Earth Economics, Basque Centre for Climate Change and Instituto De Ecologia A.C.

et al 2015). With respect to the most appropriate of these models, Volk (2013) noted that a deficit currently exists in the research to provide guidelines or protocols for model selection. Lacking a more structured approach, modeling decisions are likely to be driven by the management question to be answered, resource availability, expertise, and time constraints (Bagstad et al. 2013b, Boumans et al. 2015, Crossman et al. 2013).

### E. Payments for Ecosystem Services

Once it is recognized that resources such as forests have value in terms of providing ecosystem services it is often desired to translate this information into incentives or payment for the continuation of those services. Payment for ecosystem services schemes are generally defined as:

> "a voluntary transaction in which a well-defined environmental service (ES), or a form of land use likely to secure that service is bought by at least one ES buyer from a minimum of one ES provider if and only if the provider continues to supply service (conditionality)." (Wunder 2005).

Payment for ecosystem services schemes typically occur in one of three categories of 1) public payment, 2) self-organized deals, and 3) trading markets (Table 17).

**Table 17. Types of Payment for Ecosystem Services Schemes.**

| PES scheme type | Definition | Example |
|---|---|---|
| Public Payment | Direct payments from government agencies or public institutions directly to landowners/managers | USDA Conservation Reserve Program pays landowners annual rental payments to remove high priority lands from production and enhance for wildlife habitat. |
| Self-organized private deals | Individual beneficiaries contract directly with providers of ecosystem services | In the 1990s Perrier Vittel entered into long-term contracts with farmland owners surrounding their aquifers and provided payments for less intensive dairy farming, implementation of BMPs and reforestation of buffer zones. |
| Trading Markets | Formal market in which buyers and sellers voluntarily engage in monetary transactions for specific unitized service. Although program is voluntary, trading may be used to meet regulatory requirements | California Air Resources Board Cap-and-Trade Program allows carbon emitters to purchase “credits” from suppliers in order to meet cap requirements. |

Public payment programs for water quality and pollution reduction have existed for decades and have been available at both the federal and state level (Tomer and Locke 2011). These programs often provide cost-share or compensation for landowners to take measures to reduce nutrient loading, such as conservation easements for riparian buffers or instillation of BMPs to reduce runoff. Public payments are the least complex of PES schemes, but rely on the voluntary action of landowner participation and consistent funding from public agencies (Forest Trends et al. 2008).

Self-organized private deals are transactions or programs initiated by private entities and provide compensation in the form of rental payments and easements for ecosystem service providers. As listed in Table 4, one of the earliest and most-noted programs was Perrier Vittel, which provided rental payments to farmers in their watersheds for BMPs and reduced nutrient loading (Perrot-Maitre 2006). In more recent years, non-government organizations such as Environmental Defense Fund (EDF) and The Nature Conservancy have been working with corporate partners to reduce environmental impacts through supply-chain management. For example, EDF has partnered with Wal-Mart to reduce its food suppliers’ fertilizer applications in efforts to improve water quality (Environmental Defense Fund 2014). For corporations adopting environmental programs, such private deals can also provide production cost savings and reduce risks to variables such as drought.

Ecosystem Service trading markets have garnered considerable attention in recent years as a cost-effective alternative to achieving regulatory requirements, such as those associated with EPA's Total Maximum Daily Load (TMDL) program. Payment for ecosystems services trading markets have been considered and currently exist in the Chesapeake Bay watershed (CBW) in Maryland, Virginia, and Pennsylvania. Although attractive from a financial standpoint, trading markets are often more complex and require considerable dynamics in terms of having a sufficient number of trades, transaction costs, and institutional constraints (Forest Trends 2008). Most trading markets are for point-source pollution, as the regulatory requirement on identifiable entities provides the demand basis for the market. However, in the Lake Tahoe Basin, pollutant loads for stormwater have been delegated to local jurisdictions and state highway departments. The credit accounting is calculated on a catchment basis and can be accomplished through a number of technology and BMP strategies. Based on achievements in reducing loadings, jurisdictions can buy and sell credits amongst themselves in order to achieve load reduction requirements for the entire Lake Tahoe Basin (Lahontan Water Quality Control Board 2011).

## F. Conclusions

The literature discussed in this report demonstrates the potential of forests to provide water quality regulating services both generally and specifically to the CBW. However, in assessing, valuing, and developing formal programs pertaining to watershed services, the scientific community has not yet reached consensus as to conditions and characteristics that can be generalized across large landscapes. Although valuation of ecosystem services, such as those provided by forests, can be a powerful policy decision-making tool, the dynamics associated with whole- and sub-watersheds makes quantification, and therefore valuation, challenging. Continued development of more detailed and integrated models will improve the ability to quantify watershed services provided by forests. In light of these caveats and challenges, it remains true that forests are an important ecological element of the CBW and undoubtedly play a valuable role in managing and reducing non-point source pollution to the Bay.

## G. References


Anbumozhi, V., Radhakrishnan, J., Yamaji, E. 2005. Impact of riparian buffer zones on water quality and associated management considerations. Ecological Engineering. 24-5: 517-523.

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R. 2013a. A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosystem Services 5: 27-39.

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R. 2013b. Comparing approaches to spatially explicit ecosystem service modeling: A case study from the San Pedro River, Arizona. Ecosystem Services. 5: 40-50.

Barnes, M.C., Todd, A.H., Whitney L., Rebecca, B., Paul K. 2009. Forests, Water and People. United States Forest Service. Newtown Square, PA. NA-FR-01-08.

Bertule, M., Lloyd, G.J., Korsgaard, L. Dalton, J., Welling, R., Barchiesi, S., Smith, M., Opperman, J. Gray, E., Gartner, T., Mulligan J., Cole, R. 2014. Green Infrastructure: Guide For Water Management. United Nations Environment Programme. DEP/1837/NA.

Blankenship, K. 2011. After TMDL process, Bay Program finds itself at a crossroads. Bay Journal May. Seven Valleys, PA.

Boyd J. and Banzhal, S. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63: 616-626.

Boumans, R., Roman J., Altman, A., Kaufman, L. 2015. The Multiscale Integrated Model of Ecosystem Services (MIMES): Simulating the interactions of coupled human and natural systems. Ecosystem Services 12: 30-41.

Buckley, M., Souhlas, T., Hollingshead, A., 2011a. Economic Benefits of Green Infrastructure Chesapeake Bay Region. Final Report. ECONorthwest. Eugene, OR.

Buckley, M., Souhlas, T., Hollingshead, A., 2011b. Economic Benefits of Green Infrastructure Great Lakes Region. Final Report. ECONorthwest. Eugene, OR.

Burke, D.G., and Dunn, J.E. 2010. A sustainable Chesapeake: Better Models for Conservation. The Conservation Fund, Arlington, VA.

Burkhard, B., Crossman, N., Nedkov, S., Petz, K., Alkemade, R., 2013. Mapping and modeling ecosystem services for science, policy and practice. Ecosyst. Serv. 4, 1–3.

Calder, I.R. 2002. Forests and Hydrological Services: Reconciling public and science perceptions. Land Use and Water Resources Research. 2: 1-12.

Chesapeake Bay Commission 1987. Chesapeake Bay Agreement. Retrieved from http://www.chesapeakebay.net/content/publications/cbp_12510.pdf.

Chesapeake Bay Commission. 2013. Crediting Conservation: Accounting for the Water Quality Value of Conserved Lands Under the Chesapeake Bay TMDL. White Paper. Annapolis, MD.

Chesapeake Bay Program. 2015a. Tracking the Progress: Protected Lands. Retrieved from http://www.chesapeakebay.net/indicators/indicator/preserving_lands.

Chesapeake Bay Program 2015b. Executive Summary of Management Strategies: Conserved Lands. Backgrounder. Annapolis MD.

Corbett, C.W., Wahl, M., Porter, D.E., Edwards, D., Moise, C. 1997. Nonpoint source runoff modeling: A comparison of a forested watershed and an urban watershed on the South Carolina Coast. Journal of Experimental Marine Biology and Ecology. 231-1: 133-149.

Costanza R., d'Arge, R., de Groot, R.S., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton P., van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature, 387: 253–260.

Crossman N.D., Burkhard B., Nedkov, S., Willemen, L., Petz, K., Palomo, I., Drakou, E.G., Martin-Lopez, B., McPhearson, T., Boyanova, K., Alkemade, R., Egoh, B., Dunbar, M.B., Maes, J. 2013. A blueprint for mapping and modeling ecosystem services. Ecosystem Services. 4: 4-14.

Daily G.C., Polasky S., Goldstein J., Kareiva P.M., Mooney H.A., Pejchar L., Ricketts T.H., Salzman J., Shallenberger R., 2009. Ecosystem services in decision making: time to deliver. Frontiers in Ecology and the Environment 7: 21–28.

Environmental Defense Fund 2014. EDF launches initiative to reduce fertilizer pollution from commodity grain crops. Retrieved from: http://www.edf.org/media.

Environmental Protection Agency. 2010. Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment. Final Report. Washington D.C.

Farber, S., Costanza, R., Childers, D.L., Erickson, J., Gross, K., Grove, M., Hopkinson C.S., Kahn J., Pincetl S., Troy, A., Warren, P., Wilson, M. 2006. Linking Ecology and Economics for Ecosystem Management. BioScience. 56-2: 121-133.

Firehock, K. and Kline C. 2013. Evaluating and conserving green infrastructure across the landscape. The Green Infrastructure Center Inc. Charlottesville, VA.

Forest Trends and the Katoomba Group 2008. Payments for Ecosystem Services. A primer. Washington D.C. DEP/1051/NA/

Gartner, T., Mulligan, J., Schmidt, R. 2013. Natural Infrastructure: Investing in Forested Landscapes for Source Water Protection in the United States. 2013 World Resources Institute. Washington D.C.

Gilbert, D., Kyle, P., McCoy, A., 2012. Tracking Healthy Waters Protections in the Chesapeake Bay Watershed. Report presented to The Nature Conservancy. Thomas Jefferson Program in Public Policy at the College of William & Mary. Williamsburg, VA.

Hamel, P., Chaplin-Kramer, R., Sim, S., Mueller, C., 2015. A new approach to modeling the sediment retention service (InVEST 3.0): Case study of the Cape Fear catchment, North Carolina, USA. Science of The Total Environment 524-525: 166-177.

Hanson, C., Talberth, J., Yonavjak, L. 2011. Forests for Water: Exploring Payments for Watershed Services in the U.S. South. World Resources Institute Issue Brief #2. Washington DC.

Hively, W.D., Hapeman, J.C., McConnell, L.L., Fisher, T.R., Rice, C.P., McCarty, G.W., Sadeghi, A.M., Whithall, D.R., Downey, P.M., Nino de Guzman, G.T., Bialek-Kalinski, K., Lang, M.W., Gustafson, A.B., Sutton, A.J., Sefton, K.A., Harman Fetcho, J.A. 2011. Relating nutrient and herbicide fate with landscape features and characteristics of 15 subwatersheds in the Choptank River watershed. Science of the Total Environment. 409: 3866-3878.

Johnson, S.R., Burchell II, M.R., Evans, R.O., Osmond, D.L., Gilliam, W.J. 2012. Riparian buffer located in an upland landscape position does not enhance nitrate-nitrogen removal. 52: 252-261.

Lahontan Water Quality Control Board and Nevada Division of Environmental Protection. 2011. Lake Clarity Crediting Program Handbook for Lake Tahoe TMDL Implementation v0.99 Prepared by Environmental Incentives, LLC. South Lake Tahoe, CA.

Lele, Sharachcharndra. 2009. Watershed services of tropical forests: from hydrology to economic valuation to integrated analysis. Current Opinion in Environmental Sustainability. 1: 148-155.

Lorz, C., Volk, M. and Schmidt, G. 2007. Considering spatial distribution and functionality of forests in a modeling framework for river basin management. Forest Ecology and Management 248:17-25.

Lowrance R., Altier L.S., Newbold D.J., Schabel R.R., GRoffman P.M., Denver J.N., Corell D.L., Gilliam J.W., Robinson J.L., Brinsfield R.B., Staver K.W., Lucas W., Todd A.H. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21: 687-712.

Majanen, T., Friedman, R., Milder J. C., 2011. Innovations in Market-Based Watershed Conservation in the United States. Eco-agriculture Partners Washington D.C.

MA, 2005. MA, Millennium Ecosystem Assessment. Ecosystems and human wellbeing: current state and trends. Island Press, Washington DC.

Mittman, T., Kloss, C. 2014. The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA. Environmental Protection Agency. EP-C-11-009.

Neary, D.G., Ice, G.G., Jackson, R.C. 2009. Linkages between forest soils and water quality and quantity. Forest Ecology and Management. 258: 2269-2281.

Norton, M.M. and Fisher, T.R. 2000. The effects of forest on stream water quality in two coastal plain watersheds of the Chesapeake Bay. Ecological Engineering 14: 337-362.

NYC Environmental Protection 2010. Green Infrastructure Plan. New York Department of Environmental Protection. New York, NY.

Ojea, E., Ortega, J.M., Chiabai, A. 2012. Defining and classifying ecosystem services for economic valuation: The case of forest water services. Environmental Science and Policy 19: 1-15.

Perrot-Maitre, D. 2006. The Vittel payments for ecosystem services: a “perfect” PES case? International Institute for Environment and Development, London, UK.

Reilly, T.E., Plummer, L.N., Phillips, P.J. and Busenburg, E. 1994. The use of simulation and multiple environmental tracers to quantify ground water flow in a shallow aquifer. Water Resources Research 30: 421-433.

Sanchez-Canales, M., Lopez, Benito, A., Passuello, A., Terrado, M., Ziv, G., Acuna, V., Schumacher, M., and Elorza, F.J. 2015. Sensitivity analysis of a sediment dynamics model applied in a Mediterranean river basin: Global change and management implications. Science of the Total Environment. 502: 602-610.

STAC (Chesapeake Bay Program Scientific and Technical Advisory Committee). 2012. The role of natural landscape features in the fate and transport of nutrients and sediment. STAC Rtp. 12-04, Edgewater, MD. 27 pp.

Talberth, J., Mulligan J., Bird, B., Gartner, T., 2013. A Preliminary Green-Gray Analysis for the Cache la Poudre and Big Thompson Watersheds of Colorado's Front Range. Final Report. Center for Sustainable Economy.

Todd, Albert H. 1993. The Role and Function of Forest Buffers For Nonpoint Source Management in the Chesapeake Bay Basin. Chesapeake Bay Program White Paper Annapolis MD.

Tomer, M.D, Locke M.A. 2011. The challenge of documenting water quality benefits of conservation practices: a review of USDA-ARS's conservation effects assessment project watershed studies. Water Science and Technology. 64.1: 300-310.

Vigerstol, K.L., Aukema, J.E. 2011. A comparison of tools for modeling freshwater ecosystem services. Journal of Environmental Management. 92: 2403-2409.

Volk, M. 2013. Modeling ecosystem service-Challenges and promising future directions. Sustainability of Water Quality and Ecology. 1-2: 3-9.

Weller, D.E., Correll, D.L. and Jordan, T.E. 1994. Denitrification in riparian forests receiving agricultural discharges. Global Wetlands: Old World and New. 117-131.

Wunder, Sven 2005. Payments for environmental services: Some nuts and bolts. Center for International Forestry Research. Occasional Paper No. 42. Jakarta Indonesia.

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