Riparian Forest Buffers of the Susquehanna-Chesapeake Watershed: Observations, Assessments, and Recommendations

FINAL REPORT

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Protective tree tubes in a riparian forest buffer in the Mid-Atlantic Region, showing young trees and dense grass buffer.

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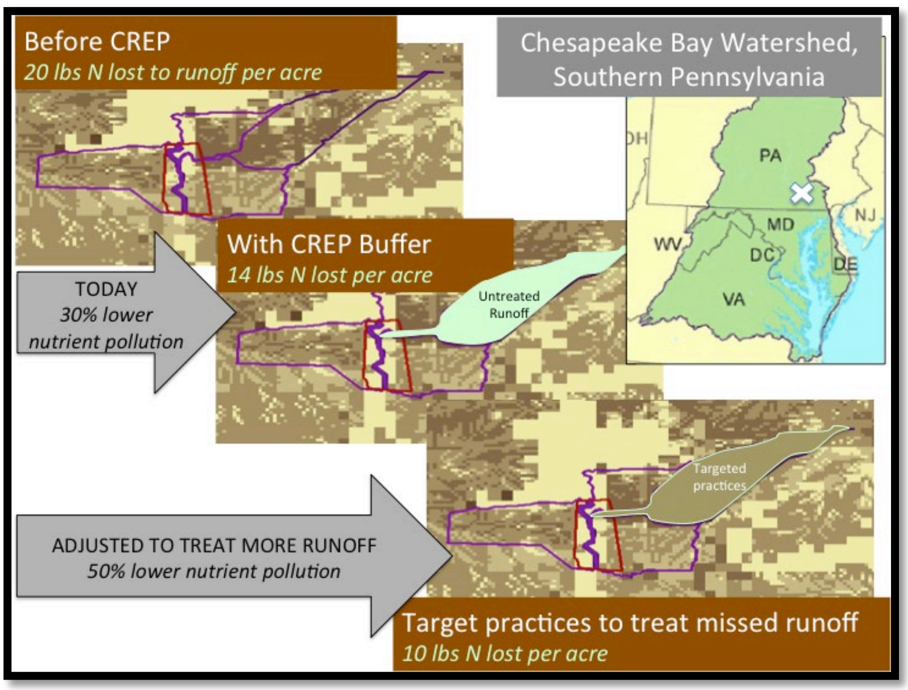
Executive Summary

USDA's Conservation Reserve Program (CRP) is the nation's flagship private-land conservation program. In the Chesapeake Bay Watershed, CRP's Conservation Reserve Enhancement Program (CREP) has played a critical role in state and federal efforts to improve the health of the Bay, having enrolled over 20,000 contracts across six U.S. states with the Susquehanna-Chesapeake Basin. Using targeted field investigations, state-of-the-art spatial analyses, and watershed modeling techniques, this project evaluated the performance of riparian forest buffers for improving water quality and documented the ecosystem services provided by CREP riparian buffers in the Chesapeake Bay watershed. Key findings include:

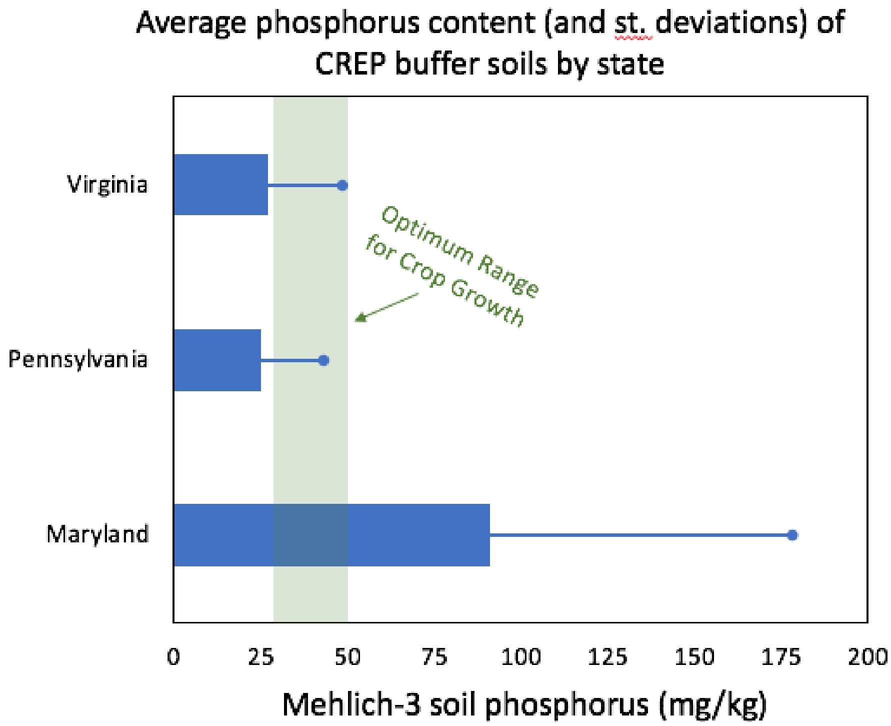
- ***Establishment of riparian buffers through CREP diversifies the array of ecosystem services provided by agriculture in the Chesapeake Bay watershed, and, as implemented, contributes positively to the goals of the Chesapeake Bay TMDL.***
- ***To be effective, riparian buffers must be implemented as part of a comprehensive conservation system***: Optimizing the performance of riparian buffers requires adaptive management that considers all practices available under CREP and coordinates with other conservation programs.
- CREP riparian forested buffers reduce nitrogen pollution from the buffer region alone by 17 to 56%, and phosphorus pollution by 4 to 20%. Similarly, grass buffers reduce nitrogen pollution by 16 to 49%, and phosphorus pollution by 4 to 18%. In fact, ***CREP buffers frequently filter more than just agricultural runoff, treating runoff from suburban developments and highways among other sources***.
- Filtration of runoff by riparian buffers is often undermined by gullies and ditches that route runoff water around the buffer. On average, these features shrink the potential for buffers to treat runoff from adjacent lands by 37%. ***Targeting maintenance of concentrated flow features (short-circuiting) is key to improving the performance of CREP buffers***.
- The majority of CREP riparian forest buffers scored in the second highest category of ecological condition assessment (Sub-optimal). ***Overall, CREP buffers compare favorably with natural riparian forest buffers within the Mid-Atlantic Region based on prior studies.***
- Based on finding from parallel studies using similar methods, ***streams flowing through extensive mature forest riparian buffers provide a much higher floodwater retention and service than streams and riparian buffers with only grass or no buffers***.
- Using riparian forest buffers and other BMPs to ***create and maintain healthy riparian ecosystems with maturing forests and soils with substantial carbon content will enhance the carbon storage and sequestration benefits of these conservation practices in agricultural landscapes.***
- CREP buffer soils may contain significant legacy phosphorus content, making them sources of phosphorus to Chesapeake tributaries. Average soil phosphorus levels in Maryland buffer soils were roughly twice what is recommended for crop production. ***New strategies are required to draw down or mitigate legacy phosphorus to ensure maximum water quality benefits from CREP buffers.***
- Better understanding not only of the site conditions, but also the upslope and upstream conditions will enhance targeting of buffers thereby improving riparian management.
- CREP buffers balance CREP design requirements, landowner goals, surrounding land use impacts, and physical site constraints. This balance makes each site unique ***making the role***

of the person providing technical assistance critical for their successful design and implementation, yet there is turnover in staff and land ownership that challenges long-term maintenance.

- ***Landowners that self-farmed lands are more capable and more likely to do maintenance on buffers***; whereas non-farming landowners need assistance, which could come from service providers and/or NGOs.
- Practitioners reported a variety of ways to enhance the existing program through interagency/organization coordination, funding for longer-term maintenance, and opportunities for product and income generation within buffers. ***A summary of recommendations follows, plus see lists of suggestions from field tours (Appendix A).***
- Opportunities exist to enhance the performance of riparian buffers, either by redesigning buffers or promoting "conservation suites" (combinations of practices). ***Comprehensive conservation planning can allow for flexibility in approaches (avoiding one-size-fits all)***.



Executive Summary Figure 1. Example of runoff analysis for one of the study sites (a CREP CP22 forested riparian buffer in Lancaster, Co. Pennsylvania), modeling the reductions in nitrogen (N) attributed to the establishment of the buffer (6 lbs N/yr lower than losses occurring without the CREP riparian forested buffer) and the potential, with targeted treatment of a concentrated flow pathway, to further mitigate N runoff. In this example, the CREP buffer has reduced total N loss in runoff by 30% (from 20 lbs total annual N loss before implementation to 14 lbs N loss after implementation), but has the potential, with additional management (e.g., grassed waterway or detention/retention structure or constructed wetland or enhanced nutrient management in adjacent fields), to further reduce annual losses of N in runoff by 50% (from 20 lbs total N loss before implementation to 10 lbs N loss per year).



Executive Summary Figure 2. Average soil test phosphorus levels (Mehlich-3) in riparian buffers sampled as part of the study, grouped by state (Maryland, Pennsylvania, Virginia). The optimum range of soil test phosphorus recommended for crop production is represented by the grey band (30-50 mg/kg).

Introduction

Background

The CREP program, administered by the U.S. Department of Agriculture's (USDA) Farm Service Agency (FSA), is a partnership between farmers, state and federal government agencies, and private groups. It was developed to assists farmers and other landowners in land conservation by minimizing erosion, restoring wildlife, and protecting ground and surface water.

The CREP project began in Pennsylvania as a response to an agriculture-related environmental issue of state and national significance identified by state government and several local nongovernmental groups. These parties developed a proposal to target environmentally sensitive and potentially wildlife-friendly acres of pastureland and cropland, including the establishment of native grass stands, riparian buffers, wetlands, wildlife habitat, grass filter strips and other land improvement practices.

Landscape attributes, habitat, and other physicochemical measures can provide important diagnostic information for interpreting biological results and water quality measures, and can be used as surrogates when biological monitoring is not feasible. Combining information on ecological condition with modeled estimates of pollutant loads can help decision makers make informed choices to locate the right places for buffers to achieve realistic ecological and water quality outcomes at feasible economic costs. Given the important role riparian buffers play in the Chesapeake Bay Total Maximum Daily Load (TMDL) and the substantial Federal investment to establish and maintain these buffers, USDA efforts seek to improve the effectiveness of buffer site location, design, and maintenance. The primary goal of this project was:

> *To improve the cost-effectiveness of Conservation Reserve Program (CRP)-funded riparian buffers by evaluating the effectiveness of current projects across the Chesapeake Bay watershed and developing strategies to enhance the targeting, implementation, and management of CRP buffers.*

USDA wanted to evaluate available monitoring, assessment, and implementation practices for buffers so that landowners and watershed stakeholders can use the information to make improvements in buffer programs, determine the most effective and efficient methods of implementation and maintenance, and to optimize the gain in benefits from the resources required to operate these programs.

Under CREP and CRP, riparian forest buffers (CP22) have the following criteria (partial list, USDA no date):

- 10-15 years of annual rental payments with an additional 20% Rental Rate Incentive
- Payments covering up to 90% of the eligible costs of establishing the practice
  - 50% from a Cost-Share Payment and
  - 40% from a Practice Incentive Payment (PIP)
- Sign-up Incentive Payment (SIP) up to $100/acre
- Meet eligible land and agricultural use conditions.
- Not be less than 35 ft (11 m) and not more 100 ft (31 m) (or 30% of the floodplain width)
- No harvesting or grazing in buffer area

Project Objectives

OBJECTIVE 1 – ASSESS THE WATER QUALITY BENEFITS AND OTHER ECOSYSTEMS SERVICES PROVIDED BY CRP-FUNDED BUFFER PROJECTS IN THE CHESAPEAKE BAY WATERSHED.
A combination of field assessment, remote sensing, and watershed modeling were used to:
1) assess the placement of CRP projects relative to concentrated hydrologic flow pathways that they should be expected to intercept,
2) summarize the range of field conditions and services provided by CRP riparian forest buffer (CP22) and riparian grass buffer (CP21) projects,
3) quantify the range of nutrient and sediment reduction benefits of current CRP projects, and
4) assess the potential for improved placement, construction, and maintenance of these projects.

Efforts under Objective 1 used best available sources of data and readily available models, some of which may not provide sufficient resolution or representation of the processes needed to accurately evaluate buffer performance in certain areas. For instance, it was anticipated that hydrologic flow pathways in flatter areas in the Atlantic coastal plain would be poorly delineated, requiring follow up efforts under Objective 2 to complete this assessment.

Sub-objective 1.1. Evaluate the placement of CRP buffers relative to hydrologic flow pathways
A primary intended role of riparian buffers and grass filters is to intercept surface runoff and groundwater flow pathways, helping to diffuse flows, promote sedimentation, and enhance denitrification. Direct measurement of all of these processes is not possible without intensive field monitoring. However, watershed modeling, supported by high-resolution remotely sensed data, can be used to determine whether CRP projects are undermined, or bypassed, by hydrologically active flow pathways. Ideally, buffers and filters should be sited so that they best intercept hydrologic flows from agriculture fields and other sources of sediment and nutrients.

Sub-objective 1.2. Assess the range of field conditions and services provided by CRP buffer projects in the Chesapeake Bay watershed
A subset of CRP riparian buffers and grass filters in the Chesapeake Bay watershed were sampled to assess their condition, local context, and range of ecosystem services that they provide. A stratified, random sampling, based upon major physiographic and management factors was used to identify approximately 150 projects across all six Susquehanna-Chesapeake states where field visits were used to survey site conditions. At all sites, a survey of farm management, up-gradient nutrient and sediment sources, CRP project condition, and concentrated flow pathways were assessed. At all sites, an evaluation of riparian condition was assessed using the Stream-Wetland-Riparian Index (SWR) to determine condition, and to consider what ecosystem services were present. The SWR provided concurrent estimates of condition for in-stream, floodplain wetland, and riparian corridor ecosystems within a 100 m x 100 m plots at each site. An integrated stressor checklist was used to examine impacts on all habitat types simultaneously, including buffers out to 300 m. Primary stressors included hydrologic modification, eutrophication, and sedimentation.

Sub-objective 1.3. Quantify the range of nutrient and sediment reduction benefits of current CRP projects and assess the potential for improved placement of these projects.
The Soil Water Assessment Tool (SWAT) was used to quantify nutrient and sediment reduction benefits of CRP projects within four CEAP/LTAR watersheds (Spring Creek, Mahantango, Conewago, Choptank). Using the datasets compiled under Sub-objective 1.1 and 1.2, a version of SWAT best suited to the hydrology of the Chesapeake Bay watershed and biogeochemical processes occurring within buffer areas will be run to quantify nutrient and sediment loads under three scenarios: 1) no CRP buffers/filters, 2) current CRP buffer/filter projects, and 3) improved siting of CRP buffer/filter projects.

OBJECTIVE 2 - BETTER BUFFER SITING AND DESIGN CRITERIA FOR BUFFERS UNDER CRP

Sub-objective 2.1. Chesapeake Bay watershed-wide estimates of buffer effectiveness with enhanced hydrology, nutrient, and riparian modules
The project team carried out a robust assessment of CRP riparian buffers and grass filters across the Bay watershed, expanding initial work under Sub-objective 1.3 and building in advanced routines to more accurately, and precisely, represent the processes occurring in buffers. The survey of CRP sites under objective 1.2 anticipated that Chesapeake Bay watershed-wide improvements to DEMs (expected from the Chesapeake Bay Program in 2016), and remotely-sensed estimates of nutrient and sediment sources (aerial photographs, land cover maps) would be used to initialize SWAT across the Chesapeake Bay watershed. As part of this effort, a suite of routines was incorporated into SWAT that better describe surface hydrology, riparian processes, and interactions with up-gradient management.

OBJECTIVE 3 - Communicate Findings and Solicit Input and Recommendations from Relevant Agencies, Organizations, and Landowners.

Sub-objective 3.1. Seek input from practitioners and decision-makers about how to enhance the implementation and maintenance of riparian forest buffers and other conservation practices.
Webinars, technical presentations, scientific papers, and field tours were used to both publicize the results of the project, and to garner input on how to improve the program.

Methods

Buffer Site Selection and Sampling Criteria

Site selection began by considering the full listing and GIS coordinates of all CREP Riparian Forest Buffers (CP22) in the Susquehanna-Chesapeake Watershed as the available population. This listing was provided by the Farm Service Agency. With nearly 20,000 contracted projects available within the watershed, we used a screening process to reduce the number of sites down to about 8,000. Criteria used to reduce the sample population from the total population of riparian forest buffers included the following (number of contracted buffer projects, as GIS polygons):

- within the Susquehanna-Chesapeake Watershed (20,814)
- with an expiration date of 2017 or later, to allow access (9,985)
- adjacent to riverine systems (< 100 m, 7,832)
- away from coastal features (> 300 m, 7,647)

The sampling scheme consisted of making a stratified, random selection of 300 sites from the 7,647 projects (Figure 1). The number of selected sites was doubled to allow of non-inclusion in the sample). We sought equal numbers of sample sites per stratum (n=300, 60 sites per stratum; 30 sites per stratum was the target for field study). Strata were defined by stream order (headwaters *vs.* mainstem, Strahler classification) and four ecoregions (physiographic regions) within the states of PA, MD, and VA (Table 1).

We encountered a few issues before, during, and after site surveys. Certain buffers were too small for field sampling (less than 0.8 ha), so they were excluded. On other sites, we were denied access to the property or their landowners could not be reached through phone calls. A few alternate sites in the states of MD and VA were also assigned during the survey process by field teams from the list of 60 for that stratum. In addition, one buffer site was later discarded because of field measurement and geographic location errors. Hence, a total of 149 sites were surveyed and assessed in this study (*ca.* 30 sites per stratum, Table 1). Sites were sampled and assessed by personnel from the forestry departments of Maryland, Pennsylvania, and Virginia during summer and fall 2016. ***This sample is representative of the population of CP22 buffers in basin***.

Table 1. Number of proposed and surveyed forest riparian buffer sites.

Strata	Stream Order	Eco-Region	Number of Proposed Sites	Number of Surveyed Sites
1	Headwater	Coastal Plain	60	30
2	Headwater	Piedmont	60	30
3	Headwater	Ridge and Valley	60	28
4	Headwater	Northern App. Plateau	60	29
5	Mainstem	All Ecoregions	60	32
Total			300	**149**

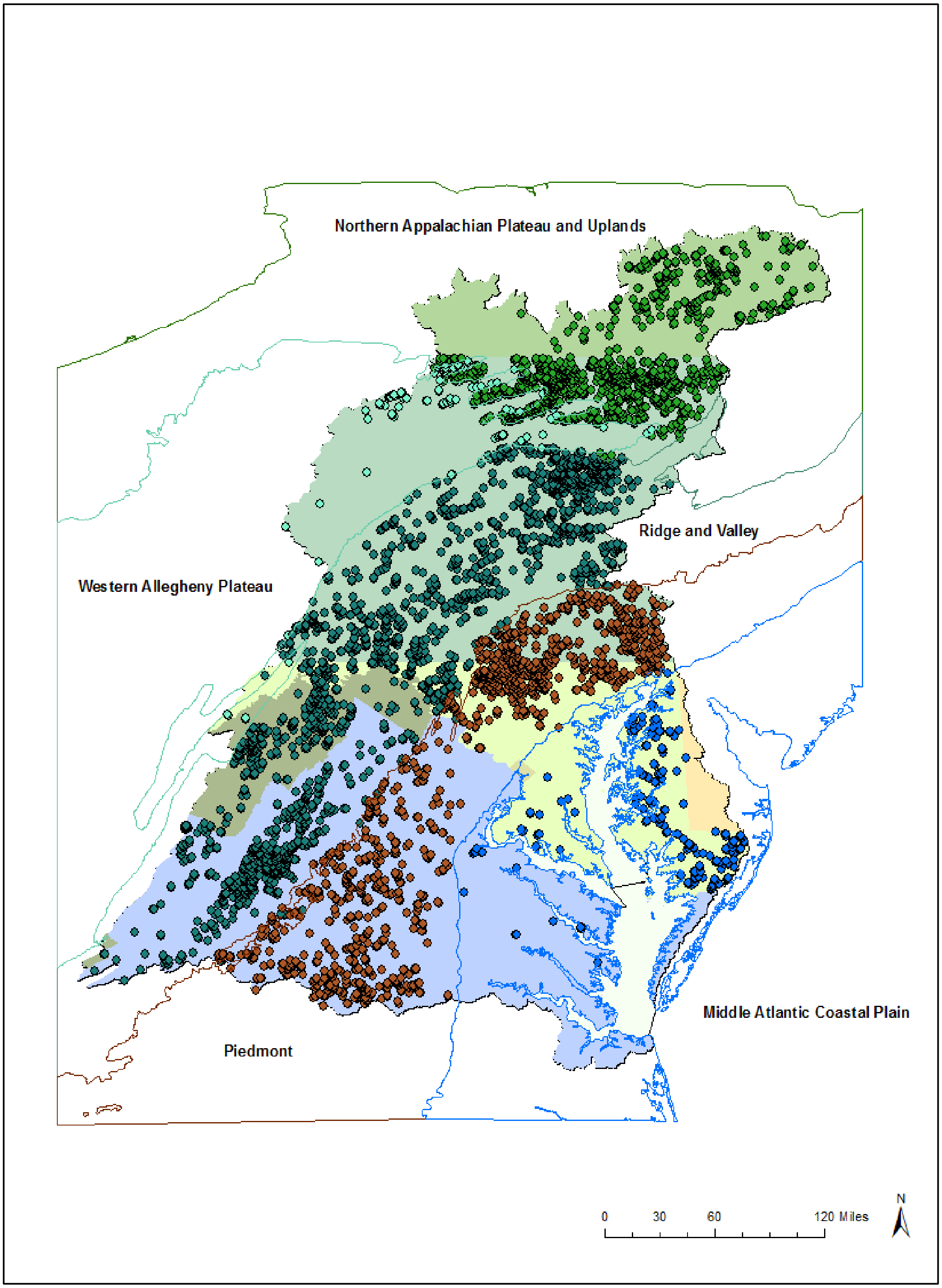


Figure 1. Spatial distribution of total number of CREP CP22 buffer projects after screening (n=7,647).

Stream, Wetland, Riparian Index Protocols and Training; Personnel

We developed a training module for field sampling that included relevant publications (Brooks et al. 2009, plus protocols and data sheets) and examples. We provided training for field crews on the SWR Index protocol at two sites in Frederick, MD in May 2016, before sampling began in MD and VA, and in State College, PA for PA crews in September 2016. Crews were assembled by state forestry agencies for Maryland, Pennsylvania, and Virginia, with assistance from the U.S. Forest Service. FSA chose this approach to build capacity for riparian buffer programs within the Bay's states.

Before field sampling began, attempts were made to notify landowners of all potential field sites, and the objectives of the study. This was accomplished with cooperation from FSA, NRCS, and county-level extension personnel at all levels – federal, state, and county. In addition, field personnel visited county offices to view and/or copy files pertaining to each field site. Conservation plans, details about buffer design and installation, plant lists, maps, and aerial photographs were obtained for many of the sites. Most landowners were receptive to allowing the site visits on their properties.

Buffer sampling occurred during the summer and fall of 2016. Penn State – Riparia personnel were available by phone or email to respond to questions from the field; fewer than five requests for clarifications occurred. Field crews submitted scanned and paper copies of field sheets, site photographs, and supplemental information about buffer contracts obtained from local agency offices. As field data were received, Riparia personnel examined the data for each site to make sure all or most of the requested data were present. Results of this project's field data were compared to existing sets of SWR reference sites across the Chesapeake Bay watershed, the latter of which are held by Riparia at Penn State from prior studies (Brooks et al. 2006, Brooks et al. 2009, Brooks et al. 2011).

Although grass buffers were not targeted in this study, we considered aspects of their use in the watershed. According to data received from USDA FSA, there are over 8,000 grass buffers (CP21) projects in the Susquehanna-Chesapeake Watershed, with most of those concentrated in the Coastal Plain. Riparian forest buffers (CP22) are distributed more evenly across ecoregions.

Hydrologic Routing from Contributing Areas through Buffers

An assessment of contributing drainage areas to CREP buffers was conducted in order to determine the presence of concentrated flowpaths and bypass features that may affect the effectiveness of riparian forest buffers within the Chesapeake Bay watershed, USA. Quantitative and spatial analyses were performed on 52 CP22 buffers within the four modeled watersheds. To do this, a Chesapeake-wide LIDAR DEM was developed for the project, specifically to capture the nuances of the low relief landscape. The LiDAR based DEM is a high-resolution dataset with a vertical accuracy of ≤ 0.15 m and a pulse density of ~2.8 pts/m2 (~ 0.35 m post spacing). This dataset is more precise and provides more information that a typical 10m or 30m DEM.

A combination of ArcGIS and the System for Automated Geoscientific Analyses (SAGA) were used to develop two topographic metrics based on the 3m-DEM derived from LiDAR data. First, the potential "topographic" contributing drainage area, was determined using a flow accumulation technique that traces the flow across each cell in a DEM separately until flow finally leaves the DEM. A modification of this called the Topographic Openness Index (Wallace et al., 2018), which expresses the dominance (convexity) or enclosure (concavity) of a landscape location, was used to assess flow patterns within the potential "topographic" contributing drainage area and identify concentrated flowpaths and other bypass features. The effective contributing drainage area was then created by subtracting from the potential "topographic" contributing drainage area those areas that appear to bypass the buffer via concentrated flowpaths or other bypass features. The two drainage areas were calculated for the 52 selected buffers within the three higher relief watersheds of PA (Conewago Creek, Mahantango Creek and Spring Creek) and the low relief landscape of the Tuckahoe watershed, a 371 km^2 subwatershed of the CEAP Choptank watershed in Maryland.

Water Quality Modeling of CREP Buffers

To assess contributions of CREP implementation to water quality, we used the widely applied hydrologic and water quality model, Soil Water Assessment Tool (SWAT; Arnold et al., 1998). Variations of the Soil Water Assessment Tool (SWAT) are commonly used for this type of project as the underlying model enables continuous simulation of watershed processes through multiple years of climate and management. SWAT tracks and reports water movement, crop growth, soil health and erosion, and nutrient fate throughout the simulation period. Topo-SWAT (Easton et al., 2008; Fuka et al., 2013) is particularly helpful for high reliefs areas with detailed land management data as it helps improve representation of hydrology at the sub-field level. This version of SWAT has been used satisfactorily in a number of cases for simulating hydrology and nutrient transport (e.g., White et al., 2011; Woodbury et al., 2014; Collick et al., 2015, 2016; Winchell et al., 2015; Amin et al., 2016; Liu et al., 2017). Topo-SWAT uses an ArcMap Toolbox (ArcGIS Desktop: Release 10.1) module as part of the SWAT model initialization process. In particular, the toolbox module is used to generate a topographically driven soils layer based on topographic index (TI) classes, to intersect the TI and soil GIS layers into the soils layer that will be used by SWAT, and to distribute soil parameters and curve numbers across the TI classes. The area of each hydrological response unit (HRU) is then defined by the intersection of land use and TI class. The HRUs define smallest calculation unit of the simulation model.

BASELINE SIMULATION SETUP:

Two different variations of the model were applied to account for physiographic differences in the watersheds. For the Choptank watershed in the Coastal Plain physiographic region, elevation changes are minimal and sandy soils promote infiltration excess based runoff. In this case, the standard version of SWAT was combined with the LiDAR based DEM and an effectiveness estimate included in SWAT for vegetated filter strips (VFS). This model was calibrated under climatic conditions from 2006 to 2011 for hydrology and validated from 2011-2014. Simulated N results were compared against available quarterly grab samples of organic N from 2006-2011.

The Spring Creek, Mahantango, and Conewago watersheds are located in the Ridge and Valley – karst, Ridge and Valley – nonkarst, and Piedmont physiographic regions, respectively. Their landscapes have notably higher reliefs than the Choptank watershed and also contain silty loam and clay soils that help to drive runoff through saturation excess mechanisms. Accordingly, we modeled these three watersheds using Topo-SWAT, a variation of SWAT, that accounts for saturation-excess runoff by using more detailed topographic information in the input files. For elevation, the 10-m DEM developed by the U.S. Geological Survey (USGS; https://nationalmap.gov/elevation.html) was used. SWAT-delineated watershed and DEM products (slope, flow direction, flow accumulation) were then used to calculate topographic index (TI) and TI classes. TI class combines two important controls on hydrology: Upslope contributing area (α) that drains through any given point and local slope gradient (tan β) (Easton et al., 2008; Beven and Kirkby, 1979):

$$TI = ln\left(\frac{\alpha}{tan\,\beta}\right)$$

TI indicates the propensity of a landscape unit to soil saturation and runoff generation (Figure 2). The TI value for each DEM pixel was calculated then classified into ten classes of equal area:

- Class 1: Lowest TI values covering 10% of the watershed area
- Class 10: Highest TI values covering remaining 10% of the watershed area

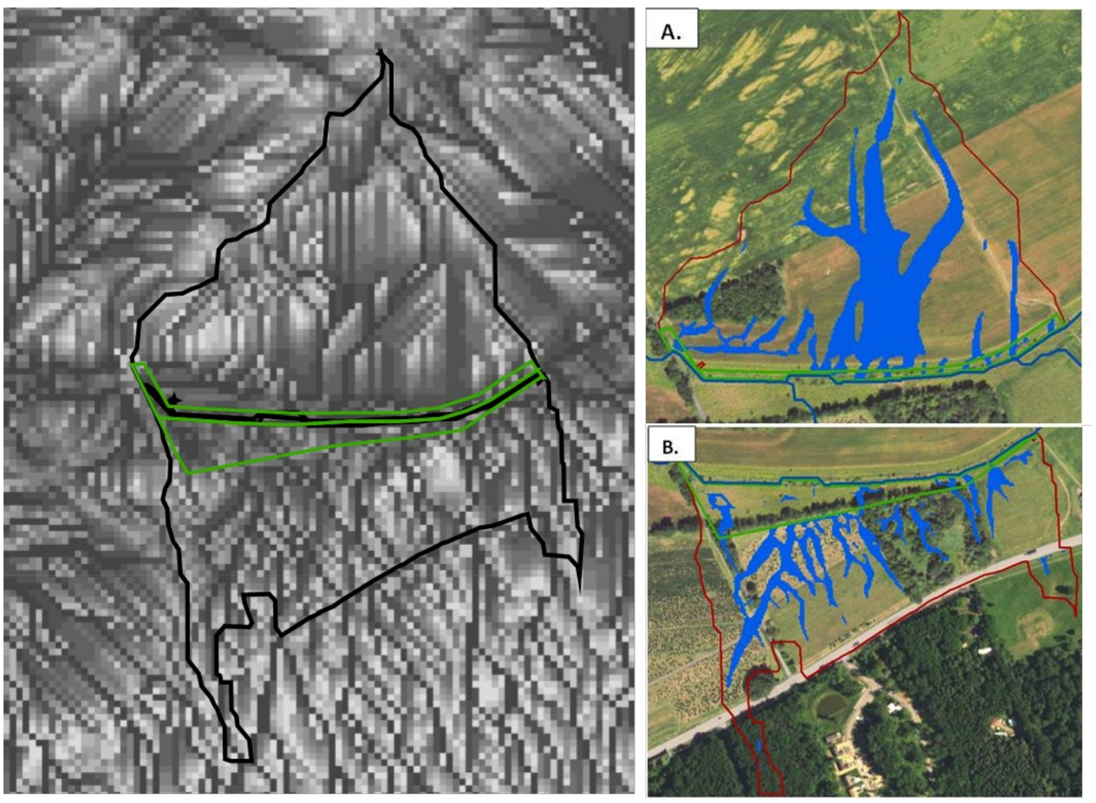


Figure 2. Topographic Index (TI) classes, as shown on the left (dark = wet, light = dry), mimics the 10-m derived flowpath accumulation into the CP22 areas. Shown is a portion of Spring Creek watershed.

Soil map and soil properties were collected from Food and Agriculture Organization (FAO-UNESCO) Digital Soil Map of the World (Land and Water Development Division, FAO, Rome, 2007; http://www.fao.org/geonetwork /srv/en/main.home#). Soil properties, including bulk density, soil texture, and hydraulic conductivity, and the curve number were then distributed across the TI classes.

The National Land Cover Dataset (NLCD) and historical aerial photos were used to identify and confirm generic land use categories in the GIS: cultivated cropland, forest, hay/pasture, and developed (Figure 3). Baseline information for the agricultural land (cultivated crops, hay/pasture) were then developed from the 2007-2014 USDA-NASS Cropland Database Layers (CLD) which subset the agricultural land into diverse crops on an annual basis, unlike the NLCD. Majority crop covers were determined at the 30-m resolution level using the ArcMap Zonal Statistics tool to summarize the CDL layers across the 2007-2014 period. Basic crop rotations (crop plantings, fertilizer/manure applications, tillage, and harvest activities) were developed initially from The Agronomy Guide (2015). Rotations differed slightly by watershed based on local practices: e.g., corn-soybean-3y alfalfa, corn-soybean-oats-3y alfalfa, corn-winter wheat-soybean-4y hay, 2y corn-soybean-4y hay, corn-soybean, and 4y corn-4y hay. Crop rotations for each 30-m GIS pixel were then assigned based on the CDL values of each pixel.

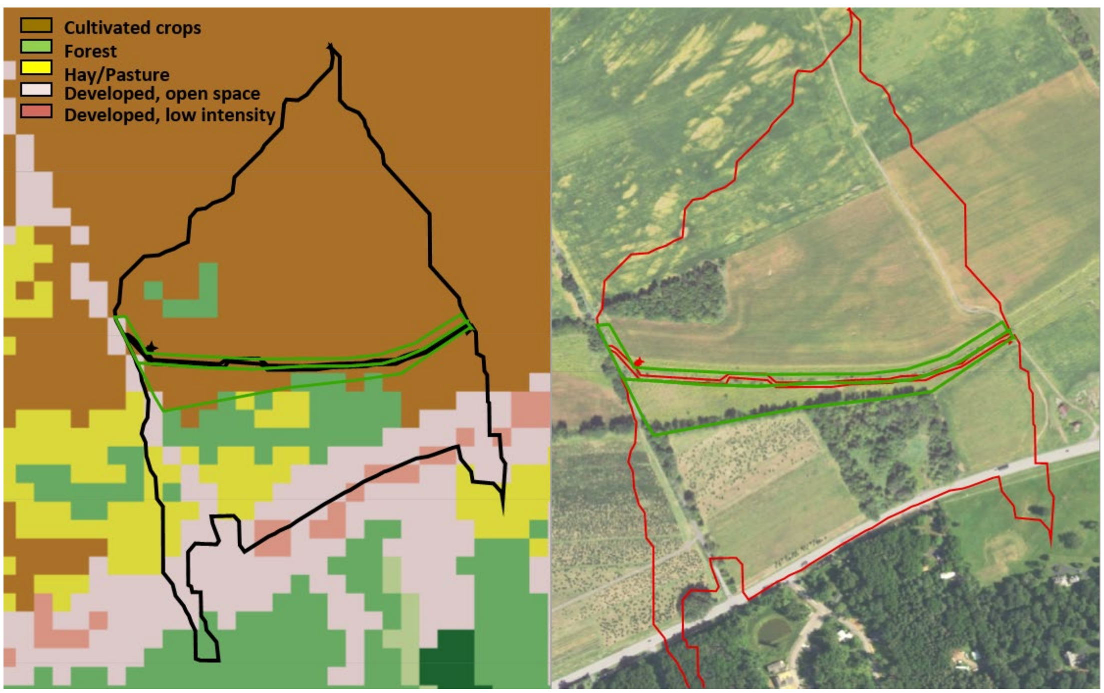


Figure 3. Generic land use from the National Land Cover Database (left) corresponds well to aerial imagery (right), as demonstrated here for one portion of the Spring Creek watershed.

Using this baseline data, a hydrological water quality model was defined and parameterized for each of the three high relief watersheds (Amin et al., 2016). For each watershed, the Topo-SWAT models were run with historical weather data provided in http://ches.communitymodeling.org/models/CBPhase5/datalibrary.php from 2007 to 2014. Average annual atmospheric deposition values were also provided by the CBP (Gary Shenk, USGS Hydrologist, personal communication, 2016). Simulation results compared positively against existing measured streamflow and water quality data, NASS cropland erosion and yield statistics, and local knowledge of the hydrological behaviors of the watersheds.

BUFFER SCENARIOS:

For all four watersheds, total nitrogen losses in runoff through the CP22 areas within the watersheds were estimated under three scenarios: baseline (previous agriculture), CP21 grass buffer, CP22 forest buffer. For the low relief watershed, the buffer effectiveness was determined by using the vegetated filter strip (VFS) module in SWAT to estimate the nutrient reductions based on user-supplied estimates of contributing area from the upslope HRU and a trapping efficiency.

For the high relief watersheds, where losses of excess phosphorus from land-applied manure are a concern, total phosphorus was also evaluated for the same three scenarios. In these watersheds we used a version of the SWAT rev 635 executable that incorporates dynamic P movement through manure degradation and soil pools, as documented in Collick et al. (2016) and Liu et al. (2017). We then represented the three scenarios by changing land use in the CP22 areas as follows:

1. Baseline scenario: maintains previous agricultural land use and management conditions
2. Grass buffer scenario: converted into established grass (Kentucky Bluegrass) with annual maintenance to represent an established CP21 grass buffer
3. Forest buffer scenario: converted into mature forest to represent an established CP22 forest buffer.

This change in land use modifies the buffer land use to simulate losses off of the buffer itself. Additionally, we multiplied the nutrient loadings coming from the upslope contributing area by buffer effectiveness estimates from the Bay model and from previous BMP effectiveness studies by our group. We combined the losses from the buffer itself with the losses that we estimated resulting from loadings filtered through the buffer to get scenario nutrient reductions.

For the three high relief watersheds, we also evaluated the impact of changing agriculture within the entire 30-m zone around the main stream networks into grass or forest buffers, not just the current CP22 areas. To do this, a 30-m buffer was generated on either side of stream network using the Proximity ArcMap tool and intersected with the land use layer. Land use areas within the buffer zone were reclassified into unique GIS records to facilitate the objectives of this project. Specifically, for this evaluation, the 3 scenarios differ only for land use within the 30-m GIS buffer zone (on each side of the stream network).

Ecosystem Services Characterization

The headwaters of watersheds comprise the terrestrial-aquatic interface between human uses of the land and the receiving waterbodies, and riparian buffers are the most appropriate places to implement Best Management Practices (BMPs). Headwaters of watersheds, which include streams, floodplains, associated wetlands and nearby uplands, typically comprise two thirds to three quarters of the spatial area of most watersheds. For example, headwater streams are directly influenced by the adjacent riparian areas, and thus, they play an important role in water quality management. These networks of streams and associated wetlands intercept and modify surface runoff and shallow groundwater entering streams that flow into larger rivers and estuaries. Headwater wetlands, floodplains, and streams provide many important ecosystem services by moderating storm runoff, processing nitrogen and phosphorus, retaining sediments, storing carbon, providing habitat, and places for recreational activities, such as angling, boating, and swimming.

Interventions to control, reduce or remediate nutrient and sediment flows into waters generate societal benefits through the enhancement or preservation of ecosystem service flows. Ecosystem services are the benefits that humans derive from ecosystems, including food, water and other provisioning services; air and water and other regulating services, cultural services (recreation, aesthetics, cultural heritage, spiritual and religious values), and supporting services (soil formation, primary production, nutrient cycling) (Boyd and Wainger 2002, MEA 2005). Approaches to estimating ecosystem services for waters of the U.S. are varied (e.g., Wardrop et al. 2011, Ringold et al. 2011, 2013, USEPA 2016). Based on the ecological assessments of conditions, we translated characterizations of ecological condition into descriptions of ecosystem services. Expected changes in ecosystem services were evaluated for **carbon storage, floodwater storage, biodiversity, water purification,** and **water-based recreation**. Most of the benefits from the suite of services considered were described using narrative or semi-quantitative ecological approaches. A considerable amount of recent research, however, has been conducted that attempts to estimate the monetary values of diverse ecosystem services. This aspect societal and monetary values for water quality benefits stemming from implementation of conservation practices was not a part of this study.

In a parallel investigation conducted by ARS and Penn State, we developed a tool to the Production and Conservation Tradeoff (PaCT) assessment tool as a rapid means for understanding tradeoffs in ecosystem services dependent on various agricultural and conservation management strategies within riparian ecosystems. Based on an extensive literature and expert panel review (Hagan et. al., TBD), the PaCT matrix contains a comprehensive ranking of all agricultural and conservation management practice and their corresponding impacts on ecosystem services on a scale of removed ecosystem service (-1), neutral impact (0), to the enhancement of an ecosystem service (+1). PaCT is able to represent independent and aggregated variables that undermine or enhance individual (ie. water quality, fish habitat) or comprehensive (ie. provisioning, regulating, supporting) services given site explicit conditions (ie. agricultural operation type, intensity of management, specific conservation goals, etc.) The lens of management implications on ecosystem services is often not considered in ecological restoration planning, thus, when tied with landscape processes assessment tools, a more wholistic suite of opportunities can be presented to landowners/conservation planners to further optimize conservation and production goals. The PaCT tool can also be applied at various scales across the landscape to understand scaling impacts of various management implications. Within this investigation, CREP program sites were assessed at 3 scales; the current CREP implementation buffer, 100 meters from top of bank and the entire contributing area to the implemented buffer.

During this investigation, PaCT was additionally used in conjunction with the AgBufferBuilder tool as a means to connect management context with landscape processes. Developed by the USDA Forest Service and National Agroforestry Center, AgBufferBuilder program aids in precision buffer placement based on site specific hydrological processes and user selected sediment and nutrient runoff capture. The tool allows for the optimization of vegetative filter strip size and placement within a selected landscape and thus presenting scale parameters for the PaCT tool to recognize tradeoffs in conservation planning methodologies based on a management and site context.

Findings

Ecological Characteristics of Buffers

From the available number of CREP buffer sites after screening (n = 7,647; Figure 1), 300 were randomly selected as possible field sites to allow for access issues. Spatial analysis and *in-situ* assessments on vegetation, stream conditions, water movement through site, and soil sampling were performed on 149 randomly selected buffer projects within the Susquehanna-Chesapeake Watershed (Figure 4). These 149 sites spanned four physiographic regions with MD containing all the sites within the Coastal Plain and PA containing the Northern Appalachian Plateau sites (Table 2).

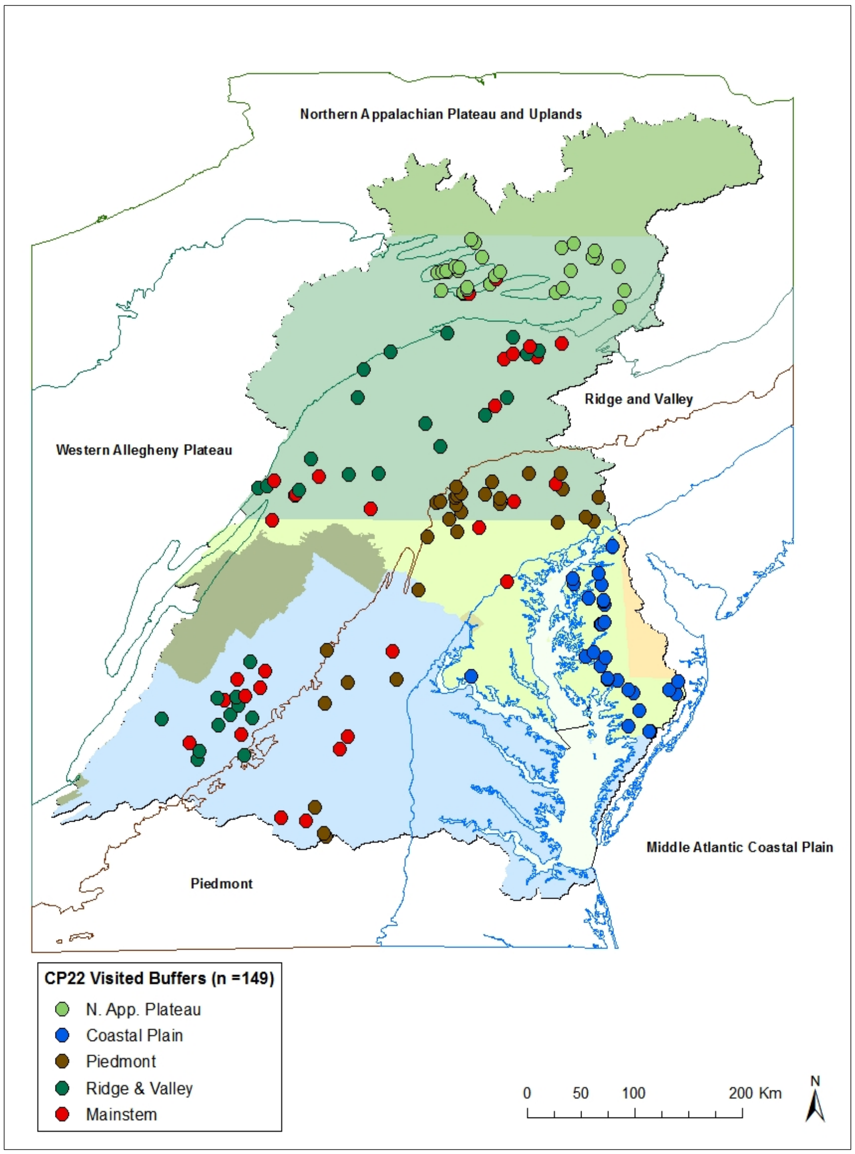


Figure 4. Spatial distribution of 149 surveyed CREP buffer sites in the Susquehanna-Chesapeake Watershed.

Table 2. Distribution of surveyed CREP buffer sites in the Susquehanna-Chesapeake Watershed.

Ecoregion	Pennsylvania	Maryland	Virginia	All Sites
Coastal Plain	-	32	-	**32**
Piedmont	20	7	12	**39**
Ridge & Valley	28	1	18	**47**
N. App Plateau	31	-	-	**31**
All Sites	**79**	**40**	**30**	**149**

Of the 149 sites sampled, 83% were located immediately adjacent to streams or ditches while the other 17% were within 10 to 100 m of a stream. In the latter cases, there was usually a natural riparian buffer in place by the stream, and the CREP buffer project was located upslope of that area. It was also observed that most of forest projects (95%) were installed parallel to streams, following the guidelines given by the Conservation Reserve Program (Conservation Practice Standard Riparian Forest Buffer – Code 391) (Figure 5).

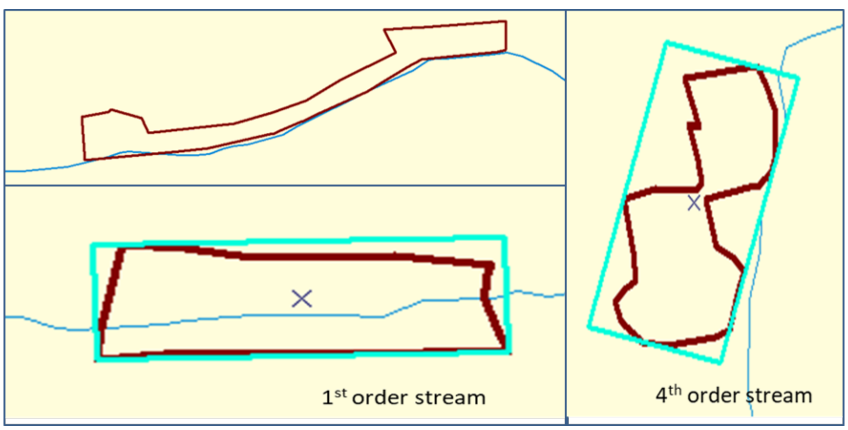


Figure 5. CREP riparian buffers found in the Susquehanna-Chesapeake Watershed. Examples show adjacency to streams, geometric buffer shape, minimum bounding rectangle, and transverse streamline across buffer site.

The average area per forest project was 2.0 ha, but projects located near mainstems covered 2.4 ha in average. Length and width of buffer polygons were determined by minimum bounding geometry, a methodology that encloses the geometric shape by its minimum bounding rectangle (Figure 5). Thus, the overall length of project sites, measured as the longer side of the resulting rectangle, averaged 344 m (range 127 to 910 m). The width of project sites, measured as the shorter side, averaged 119 m (range 29 to 710 m). Buffers located near mainstems were longer.

We found statistically significant differences on the length of buffers between mainstems and headwaters (Tables 3 & 4 and Figure 6).

No significant differences were found in size, width, and shape complexity. However, when buffer widths were adjusted (i.e., width re-calculated for buffers bisected by streams), significant differences were found between headwater and mainstem buffers ($p<0.003$). In order to better compare widths and their functions, buffer polygons were divided along streamlines and then widths adjusted according to the areas receiving runoff from just one side of the stream. About 46% of buffers located in headwaters were bisected by streams while just 12% of buffers at mainstems were bisected by streams. After adjusting widths, statistically significant narrower buffers were observed in headwaters. Additionally, adjusted buffer widths in the Piedmont and Ridge-and-Valley Ecoregions were significantly different from the Coastal Plain Ecoregion ($p<0.002$). Narrow buffers found in the Piedmont and Ridge-and-Valley Ecoregions may be associated to natural restraints. Particularly, higher slope averages (10%) were found in buffers located in the Ridge-and-Valley Ecoregion, and statistically significant differences ($p<0.0001$) were observed between these slopes and slopes from the Coastal Plain Ecoregion (Table 5 and Figure 7)

The examination of perimeter-to-area ratios, evidenced the prevalence of long, narrow buffer areas. Examples of shapes Appendix A on buffer sites visited during 3 field tours in the Mid-Atlantic Region.

Table 3. Dimensions of CREP riparian forest buffers in the Mid-Atlantic Region according to location within the watershed (headwater vs mainstem).

	Total/Average	Headwater	Mainstem	*P<*
No. Sites	149	117	32	
Area (ha)	2.0	1.9	2.4	0.200
Length (m)	344	**330**	**405**	**0.019**
Width (m)	119	114	123	0.445
Adjusted Width (m)	85	**80**	**103**	**0.003**
Perimeter to Area Ratio	0.05	0.05	0.06	0.200

*Numbers in bold indicate statistically significant differences

Table 4. Dimensions of CREP riparian forest buffers in the Mid-Atlantic Region according to stream order.

	Total/ Average	Stream Order Headwater			Stream Order Mainstem		
		1	2	3	4	5	6
No. Sites	149	68	34	15	20	9	3
Area (ha)	2.0	1.9	2.1	2.1	1.8	3.5	2.8
Length (m)	344	313	331	400	386	426	469
Adjusted Width (m)	85	**81**	**82**	**69**	**97**	**107**	**130**
Perimeter to Area Ratio	0.05	0.05	0.05	0.06	0.06	0.06	0.04

*Numbers in bold indicate statistically significant differences

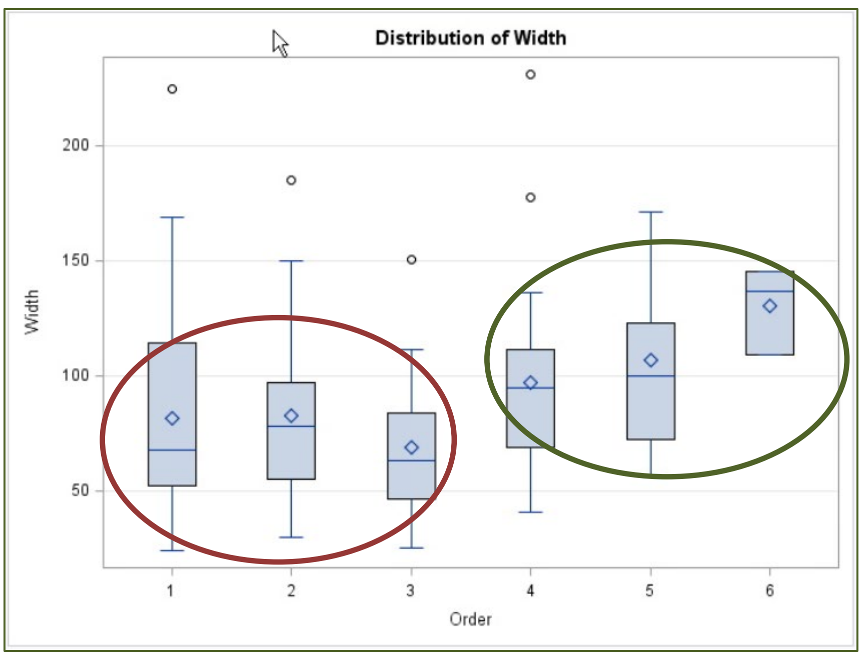


Figure 6. Distribution of buffer width according to stream order. Significant differences (*p<0.003*) in width were found between headwater (stream orders 1, 2 and 3) and mainstem (stream orders 4, 5, and 6) buffers.

Table 5. CREP riparian forest buffers located at headwaters and within the Mid-Atlantic Ecoregions.

	Headwater				*P<*
	Coastal Plain	**Piedmont**	**Ridge and Valley**	**N Appalachian Plateau**	
No. Sites	30	30	28	29	
Area (ha)	1.9	1.8	1.8	2.3	
Length (m)	284	339	367	331	
Adjusted Width (m)	**96**	**73**	**68**	82	**0.002**
Slope (%)	**1.3**	5.5	**10.0**	5.3	**0.0001**

*Numbers in bold indicate statistically significant differences

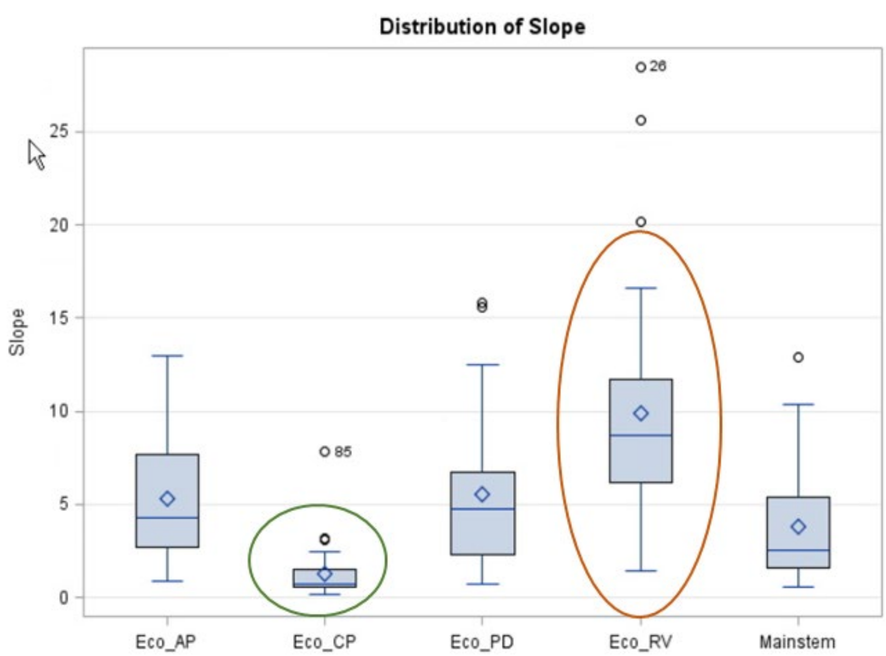


Figure 7. Distribution of slope (%) for the CREP riparian forest buffers located at headwaters (shown by ecoregion) and at mainstems. Significant differences (*p<0.0001*) were found in the percent (%) of slope between buffers located in the Ridge-and-Valley and Coastal Plain Regions.

Because the presence of hydric soils in buffers can potentially provide enhanced transformation and removal of nutrients (through denitrification for nitrogen), we examined the presence of wetlands within the buffers. Based on National Wetland Inventory mapping, 29 buffer projects - out of 149 - had wetland areas within their buffer project boundaries. The average wetland area for the 29 projects was 0.3 ha and the average area per buffer was 2.6 ha.

Ecological Characteristics of Buffers – Stream, Wetlands, Riparian Index

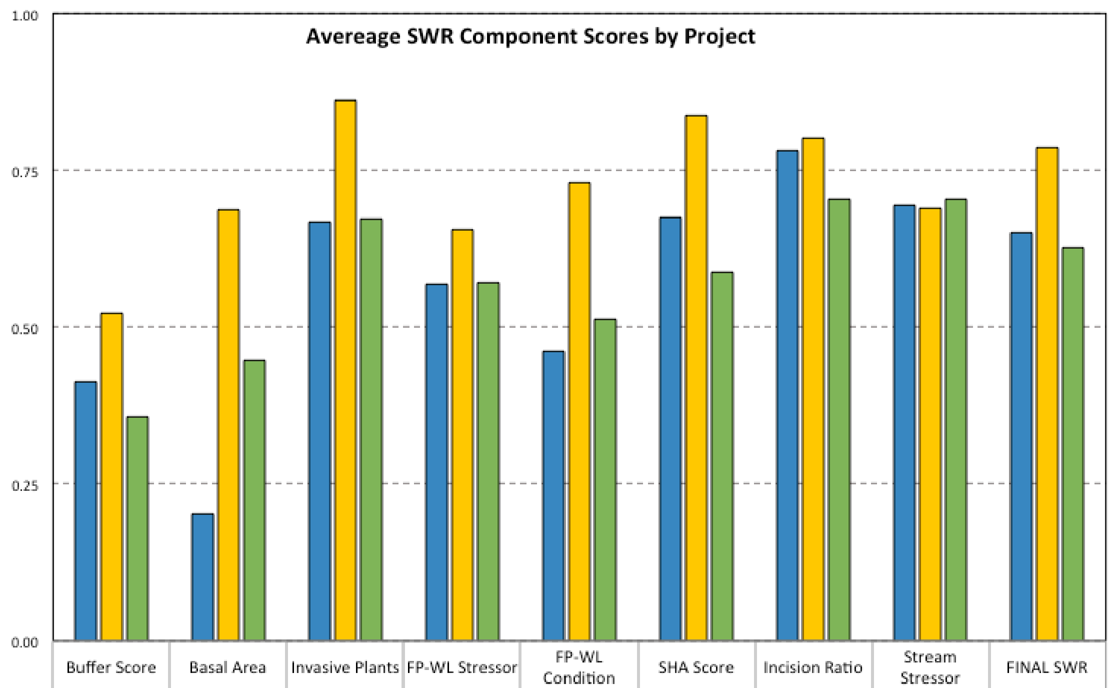
Rapid field assessments and performance results were analyzed in this study. In 2016, field crews collected ecological condition metrics at CREP contract locations across Maryland, Pennsylvania, and Virginia. These metrics were used to calculate the 7-component Stream-Wetland-Riparian (SWR) index to provide a better understanding of the ecological functions provided by these riparian buffer systems. These individual component scores and final SWR scores were then compared to wetland scores in the Riparia Reference Wetland Database that spans the same states, ecoregions, and agricultural landscapes where the surveyed CREP projects are located (www.riparia.psu.edu).

The majority of CREP riparian forest buffers scored in the second highest category of condition assessment (sub-optimal), comparing favorably with natural riparian forest buffers. Categorization terminology for placing sites into four tiers of condition was based on standard terms from ecological stream habitat assessments in which "*Optimal*" indicates a condition similar to an undisturbed old-growth forest or a native coastal plain grassland. Thus, in today's urbanized and developed landscape, "*Sub-Optimal*" is generally a high score near active agricultural land uses or low-density residential uses, "*Marginal*" indicates a category of condition for more intensive agricultural and residential uses, and "*Poor*" generally indicates places where there is considerable opportunities for habitat improvement, such as in urban and industrial dominated landscapes, and poorly managed agricultural areas (Table 3).

Table 6. Average Stream Wetland Riparian (SWR) Index final scores grouped by category and ecoregion.

Ecoregion	Final SWR Score	Optimal	Sub-Optimal	Marginal	Poor
Coastal Plain	0.59	3%	81%	16%	0%
Piedmont	0.58	3%	80%	18%	0%
Ridge & Valley	0.65	15%	79%	4%	2%
N. App Plateau	0.70	42%	45%	13%	0%
All Sites	0.63	15%	72%	12%	1%

SWR final scores from 149 CREP contract locations averaged 0.63 on a scale of 0 to 1. This is less than the 0.79 average of 521 sites assessed for the Atlantic Slope Consortium (ASC, Brooks et al. 2006, Brooks et al. 2009), and 0.65 average of 68 sites assessed for the (Penn State) Center for Nutrient Solutions (CNS, Shortle et al. 2019). Most average component scores across CREP sites were equivalent to CNS scores and less than component scores related the ASC effort (Figure 8). One notable exception was the CREP tree basal area score of 0.45, which was more than double the basal area score of sites assessed during the CNS project. SWR final and component scores related to the ASC study are likely higher than those collected at CREP contract sites because of differences in the landscape characteristics of natural riparian buffers assessed for ASC sites versus the created buffers in CREP projects. Sites assessed for the ASC project covered a variety of wetland hydrogeomorphic classifications across a range of landscape disturbance from forested to urban. CREP sites were narrowly focused on riparian floodplains in agricultural settings, likely making broad, project-wide comparisons between CREP and ASC sites somewhat misleading. These comparisons, however, do provide either a benchmark or a performance target on which to judge the success of CREP buffer projects.

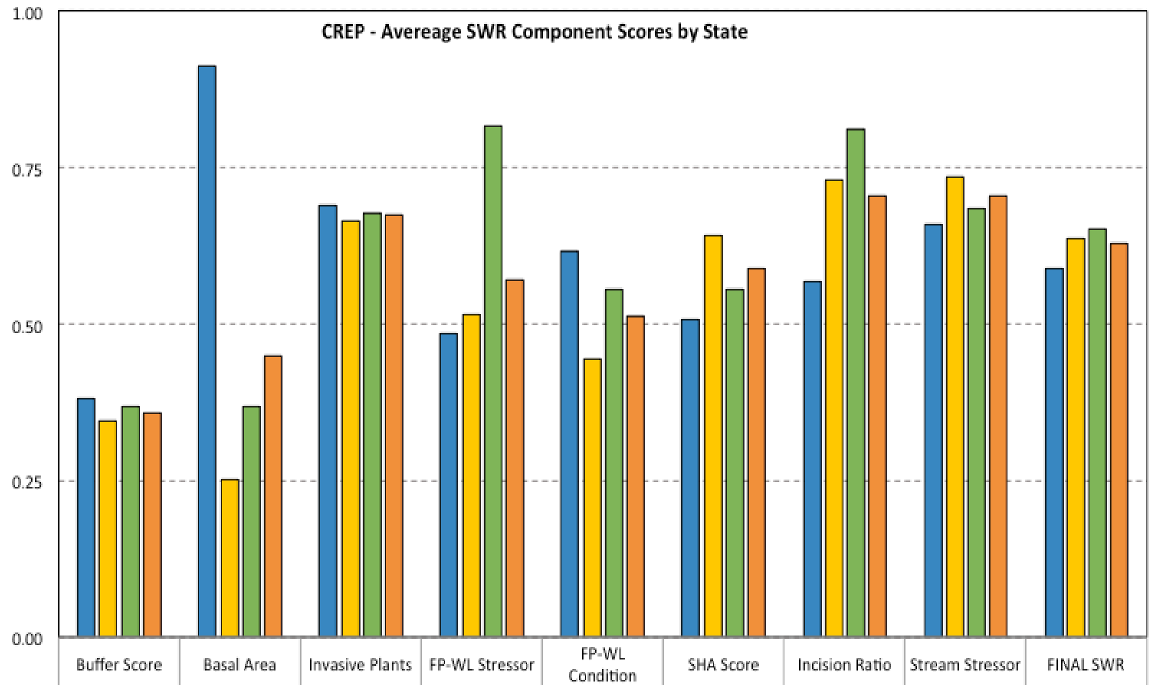


	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
CNS (68)	0.41	0.20	0.67	0.57	0.46	0.67	0.78	0.70	0.65
ASC (521)	0.52	0.69	0.86	0.66	0.73	0.84	0.80	0.69	0.79
CREP (149)	0.36	0.45	0.67	0.57	0.51	0.59	0.71	0.70	0.63

Figure 8: SWR average final and component scores for riparian sites from CREP, CNS, and ASC studies.

A closer look a state-by-state SWR final and component scores at selected CREP contract locations revealed similar average SWR final scores including 0.59 in Maryland, 0.64 in Pennsylvania, and 0.65 in Virginia. SWR component scores characterizing site buffers, invasive plants, and stream stressors all showed few differences at selected sites across the surveyed states. Basal area scores in Maryland averaged 0.91, well above the 0.25 and 0.37 average scores found in Pennsylvania and Virginia respectively, indicating much higher tree cover was present within the buffers, either planted or existing trees. Floodplain-Wetland Stressor (FP-WL) scores in Virginia averaged 0.82, which was higher than the 0.49 and 0.52 average scores found in

Maryland and Pennsylvania, respectively. Site visits determined the selected CREP contracts in Pennsylvania had higher average Stream Habitat Assessment (SHA) scores, while Virginia average the highest incision ratio score. A complete summary of state-by-state scores can be found in Figure 9 and Table 7.



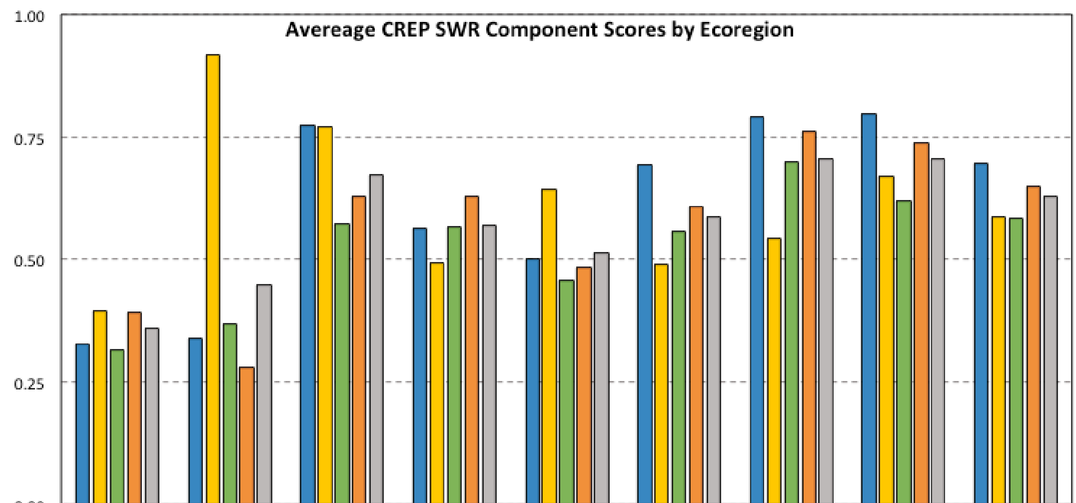
	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
CREP MD	0.38	0.91	0.69	0.49	0.62	0.51	0.57	0.66	0.59
CREP PA	0.34	0.25	0.66	0.52	0.44	0.64	0.73	0.73	0.64
CREP VA	0.37	0.37	0.68	0.82	0.56	0.55	0.81	0.69	0.65
CREP All Sites	0.36	0.45	0.67	0.57	0.51	0.59	0.71	0.70	0.63

Figure 9: Average SWR component and final scores for CREP riparian forest buffers in MD, PA, and VA.

Table 7. Average SWR component and final scores for CREP riparian forest buffers by category.

	Buffer Score	Basal Area Score	Invasive Plants Score	FP-WL Score	FP-WL Condition Score	SHA Score	Incision Ration Score	Stream Stressor Score	FINAL SWR SCORE
All Sites (149)	0.36	0.45	0.67	0.57	0.51	0.59	0.71	0.70	0.63
Headwater (117)	0.36	0.48	0.69	0.55	0.52	0.56	0.70	0.70	0.62
Mainstem (32)	0.35	0.33	0.60	0.66	0.48	0.68	0.72	0.73	0.65
Piedmont (40)	0.32	0.37	0.57	0.57	0.46	0.56	0.70	0.62	0.58
Ridge & Valley (47)	0.39	0.28	0.63	0.63	0.48	0.61	0.76	0.74	0.65
App Plateau (31)	0.33	0.34	0.77	0.56	0.50	0.69	0.79	0.80	0.70
Coastal Plain (31)	0.39	0.92	0.77	0.49	0.64	0.49	0.54	0.67	0.59
MD (39)	0.38	0.91	0.69	0.49	0.62	0.51	0.57	0.66	0.59
PA (79)	0.34	0.25	0.66	0.52	0.44	0.64	0.73	0.73	0.64
VA (31)	0.37	0.37	0.68	0.82	0.56	0.55	0.81	0.69	0.65
NWI Wetland (29)	0.34	0.32	0.67	0.54	0.46	0.66	0.75	0.79	0.66
No Wetland (120)	0.36	0.48	0.68	0.58	0.52	0.57	0.69	0.68	0.62

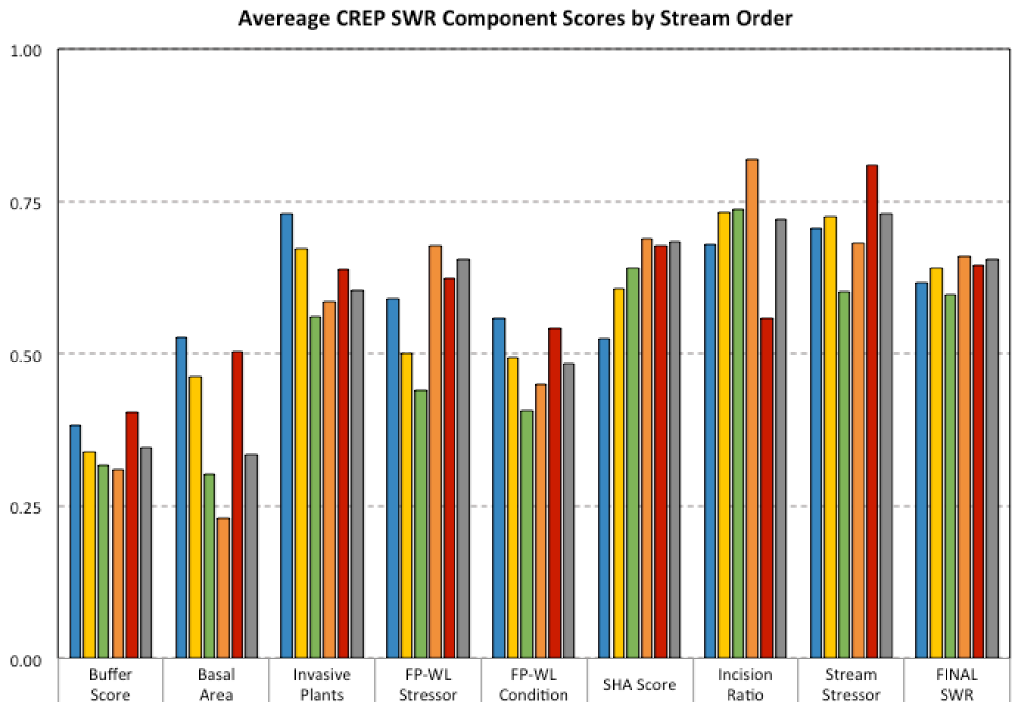
A breakdown of SWR final and component scores by ecoregion revealed the selected CREP contract locations in the Appalachian Plateau had the highest average final score of 0.70, followed by the Ridge and Valley with 0.65, with the Coastal Plain and Piedmont averaging 0.59 and 0.58, respectively. High scores for stream stressors, incision ratio, and invasive plants primarily drove the high average final SWR score in the Appalachian Plateau. CREP contract sites in the Coastal Plain received very high scores for Basal Area and Invasive Plants, while scoring in the marginal tier for site buffer composition, Floodplain-Wetland Stressors, and Stream Habitat Assessment. The distribution of average final SWR scores across ecoregions follows an expected pattern of landscape disturbance with the Appalachian Plateau experiencing the least overall disturbance and the Coastal Plain and Piedmont experiencing the highest levels of disturbance related to agriculture, roads, and urban/suburban development. A complete summary of ecoregion specific SWR component score averages can be found in Figure 10.



	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
Appalachian Plateau (31)	0.33	0.34	0.77	0.56	0.50	0.69	0.79	0.80	0.70
Coastal Plain (31)	0.39	0.92	0.77	0.49	0.64	0.49	0.54	0.67	0.59
Piedmont (40)	0.32	0.37	0.57	0.57	0.46	0.56	0.70	0.62	0.58
Ridge and Valley (47)	0.39	0.28	0.63	0.63	0.48	0.61	0.76	0.74	0.65
CREP All Sites (149)	0.36	0.45	0.67	0.57	0.51	0.59	0.71	0.70	0.63

Figure 10: Average SWR component and final scores for CREP riparian forest buffers by ecoregion.

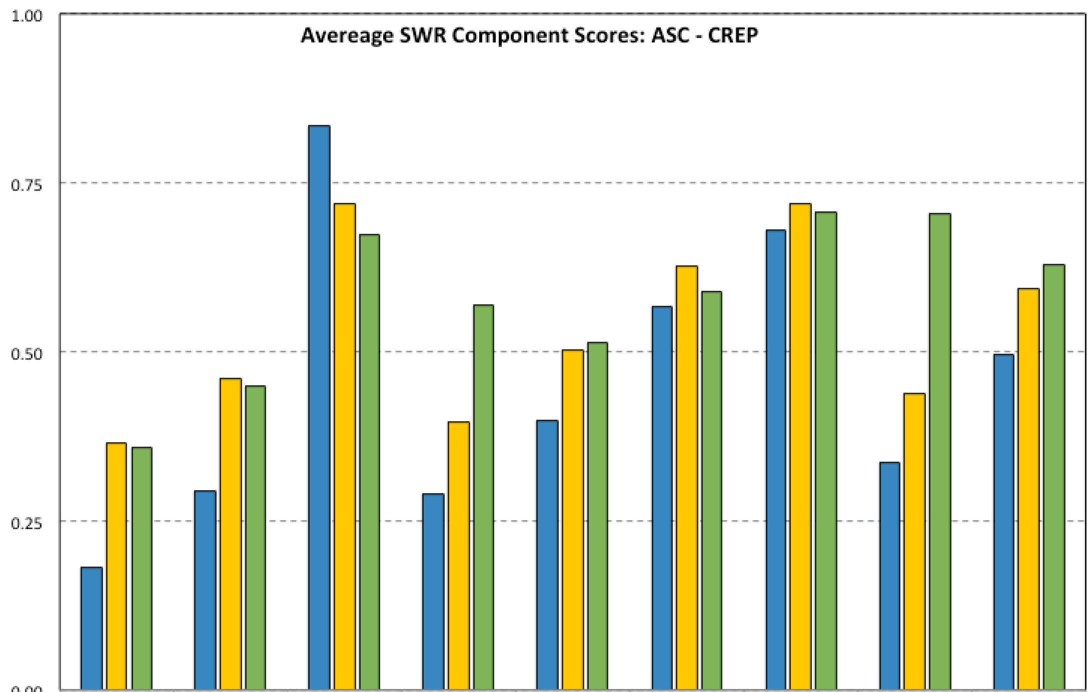
SWR final scores at CREP contract locations showed little variation at sites along different sized streams. First order streams were the most common in study with 69 sites (46%) located along these small streams. Buffer scores, Basal Area scores, and Invasive Plant scores decreased with increasing stream order with the exception of higher average scores for 5th and 6th order streams (only 12 sites occurred in this combined category). Stream Habitat Assessment scores and Incision Ratio scores generally increased with increasing stream order. Selected CREP sites along third order streams averaged the lowest Floodplain-Wetland Stressor and overall Floodplain Condition Score. Selected CREP contracts along larger 5th and 6th order streams averaged the highest buffer and Stream Stressor score, and the lowest incision ratio score. A complete summary of stream order specific SWR component score averages can be found in Figure 11.



	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
1st Order Streams (69)	0.38	0.53	0.73	0.59	0.56	0.52	0.68	0.70	0.62
2nd Order Streams (33)	0.34	0.46	0.67	0.50	0.49	0.61	0.73	0.73	0.64
3rd Order Streams (15)	0.32	0.30	0.56	0.44	0.41	0.64	0.74	0.60	0.60
4th Order Streams (20)	0.31	0.23	0.59	0.68	0.45	0.69	0.82	0.68	0.66
5th & 6th Order Streams (12)	0.40	0.50	0.64	0.62	0.54	0.68	0.56	0.81	0.65
4th, 5th & 6th Order Streams (32)	0.35	0.33	0.60	0.66	0.48	0.68	0.72	0.73	0.65

Figure 11: Average SWR component and final scores for CREP riparian forest buffers by stream order.

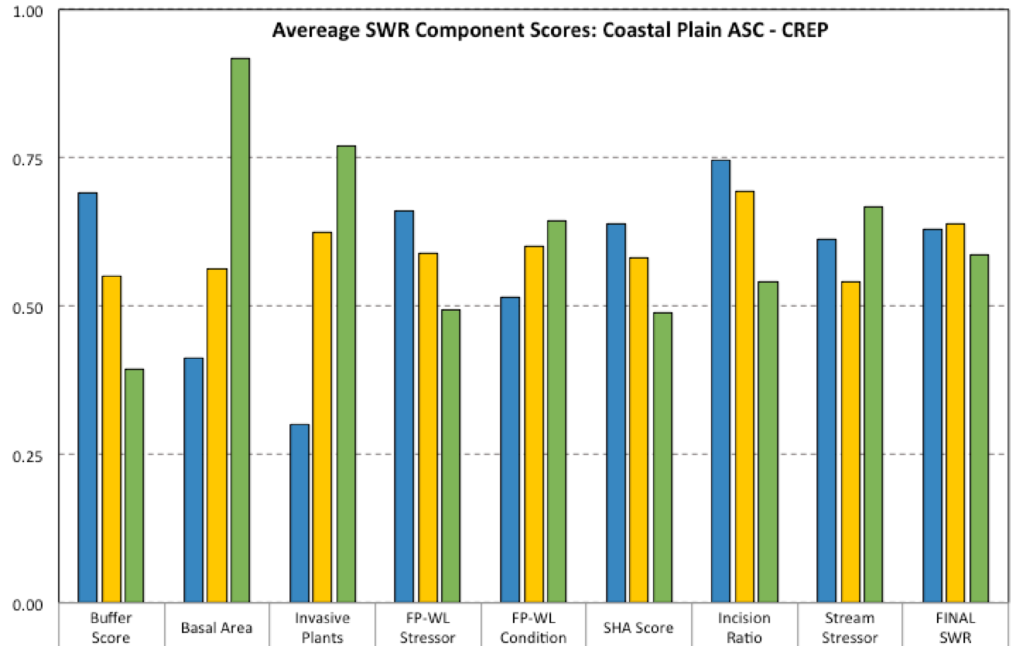
In an effort to relate sites across projects located in similar agricultural landscape settings, a comparison was made between selected CREP contract sites (149) and sites assessed in the ASC with agricultural land use greater than 50% (187) and greater than 75% (50) within a 1-km radius of the assessed site centers. CREP contracts scored the highest among this group averaging 0.63, with ASC sites in over 50% and 75% agricultural surroundings scoring 0.59 and 0.50, respectively. CREP locations scored much higher in stream stressor and Floodplain-Wetland Stressor categories compared to the ASC sites, but scored lower in the invasive plant category. This analysis highlights the benefits achieved through CREP in agricultural landscapes, and specifically identifies the success in reducing site stressors and the need to more aggressively manage invasive plants when creating and maintaining lands under CREP contracts. Figure 12 includes a complete summary of SWR component score averages using this landscape comparison metric between projects.



	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
ASC >75% Ag 1km (50)	0.18	0.30	0.83	0.29	0.40	0.57	0.68	0.34	0.50
ASC >50% Ag 1km (187)	0.37	0.46	0.72	0.40	0.50	0.63	0.72	0.44	0.59
CREP (149)	0.36	0.45	0.67	0.57	0.51	0.59	0.71	0.70	0.63

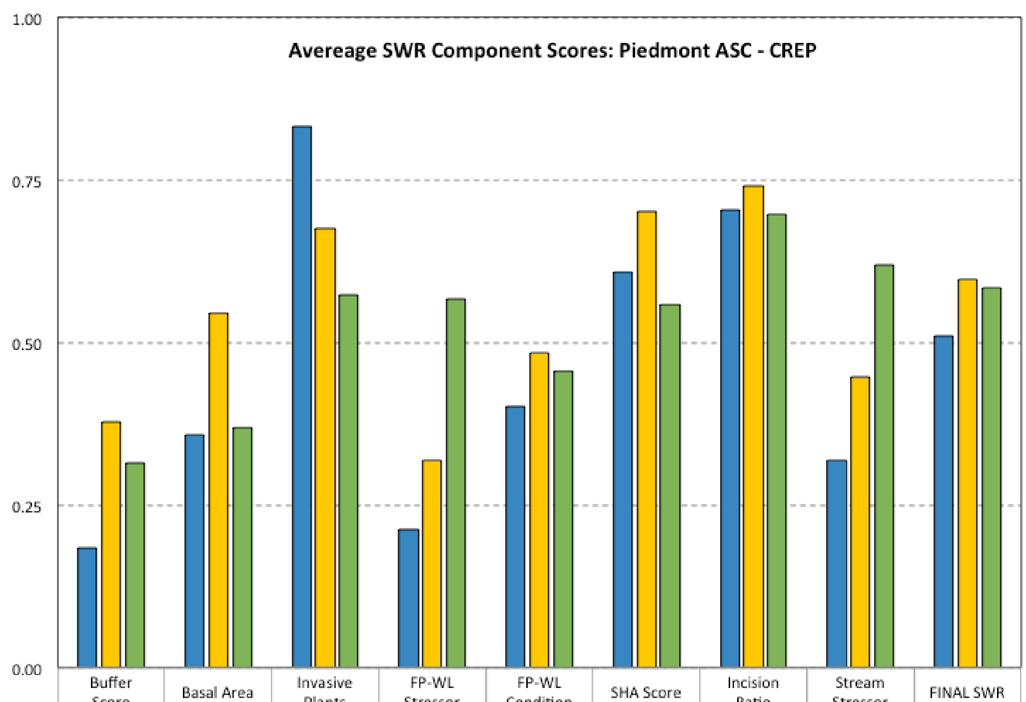
Figure 12: Average SWR component and final scores for riparian buffers between CREP and ASC Agricultural locations.

A further focus on ecoregion-specific CREP ecological benefits compared to other sites in agricultural landscapes is summarized in Figures 13, 14, and 15. In the Coastal Plain, CREP sites significantly outperform non-CREP sites with respect to Basal Area and Invasive plant scores, but have average lower scores for site buffers, Stream Habitat Assessment scores, and Incision Ratio scores.



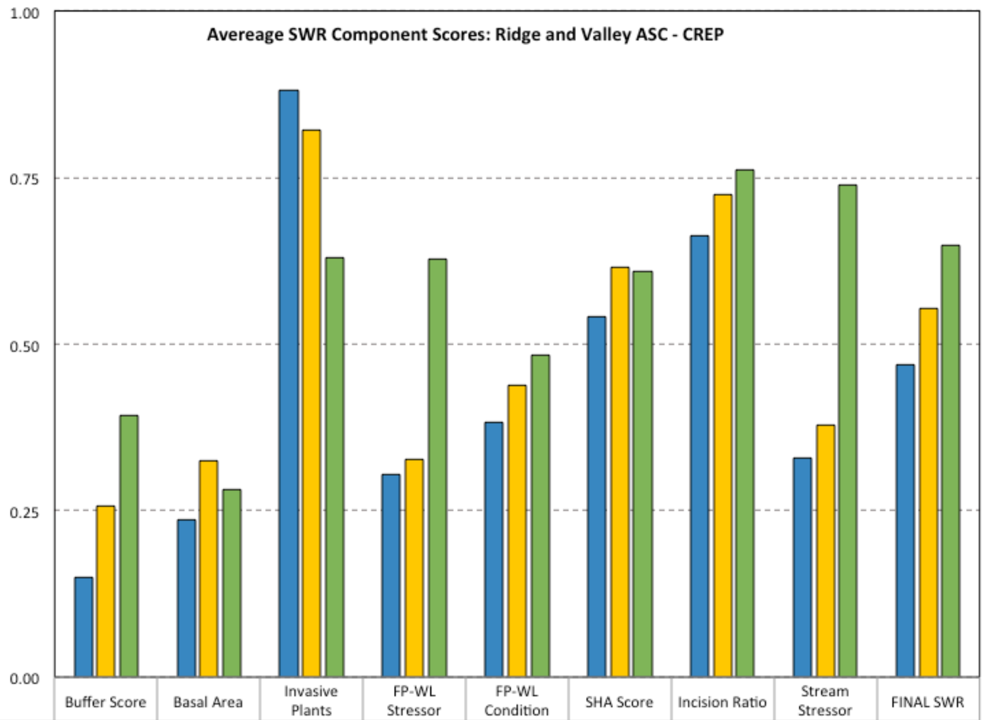
	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
ASC - Coastal Plain >75% Ag 1km (2)	0.69	0.41	0.30	0.66	0.52	0.64	0.75	0.61	0.63
ASC - Coastal Plain >50% Ag 1km (51)	0.55	0.56	0.62	0.59	0.60	0.58	0.69	0.54	0.64
CREP Coastal Plain (31)	0.39	0.92	0.77	0.49	0.64	0.49	0.54	0.67	0.59

Figure 13: Average SWR component and final scores for riparian buffers between CREP and ASC Agricultural locations in the Coastal Plan Ecoregion.



	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
ASC - Piedmont >75% Ag 1km (16)	0.19	0.36	0.83	0.21	0.40	0.61	0.70	0.32	0.51
ASC - Piedmont >50% Ag 1km (45)	0.38	0.55	0.67	0.32	0.48	0.70	0.74	0.45	0.60
CREP Piedmont (40)	0.32	0.37	0.57	0.57	0.46	0.56	0.70	0.62	0.58

Figure 14: Average SWR component and final scores for riparian buffers between CREP and ASC Agricultural locations in the Piedmont Ecoregion.



	Buffer Score	Basal Area	Invasive Plants	FP-WL Stressor	FP-WL Condition	SHA Score	Incision Ratio	Stream Stressor	FINAL SWR
ASC - Ridge and Valley >75% Ag 1km (32)	0.15	0.24	0.88	0.31	0.38	0.54	0.66	0.33	0.47
ASC - Ridge and Valley >50% Ag 1km (91)	0.26	0.33	0.82	0.33	0.44	0.62	0.72	0.38	0.55
CREP Ridge and Valley (47)	0.39	0.28	0.63	0.63	0.48	0.61	0.76	0.74	0.65

Figure 15: Average SWR component and final scores for riparian buffers between CREP and ASC Agricultural locations in the Ridge and Valley Ecoregion.

These estimates also were used to forecast changing conditions after installation of riparian buffers. Although use of forested buffers associated with the CREP program has resulted in ecological assessment scores primarily in the Sub-Optimal (Tier 2) category, with very few sites scoring in the Marginal (Tier 3) or Poor (Tier 4) categories, there is an opportunity to see increased ecological benefits by ensuring the intended buffer design and function is achieved. Because CREP buffers are located in productive agricultural landscapes often adjacent to crops, pastures, roads, and houses, most will never achieve pristine ecological scores across all measured ecological metrics simply because of their position in the landscape. Despite the inherent ecological limitations many buffer systems operate under, minor changes to initial design considerations and maintenance practices will serve to both eliminate ecological condition scores in the lowest 2 tiers and improve ecological conditions in buffer systems already achieving scores in the Optimal and Sub-Optimal categories.

To illustrate potential realistic improvements to buffer ecological condition scores, assume two improvements where sapling survival increased and invasive vegetation cover decreased only in sites surveyed during this study where these two metrics received low scores. With these improvements, only the lowest scoring condition metrics associated with tree density and invasive vegetation cover would improve. First, consider a scenario reflective of potential improvements to sites at the beginning of the contract (young trees), and second, consider a scenario reflective potential improvements realized with a mature forested buffer.

In the first scenario, assume a newly planted forested buffer system with high sapling survival rates and low invasive vegetation cover would receive the following minimum ecological condition metric scores: buffer score ≥ 0.3, basal area score ≥ 0.5, invasive cover score ≥0.75, floodplain-wetland stressor score ≥ 0.5, stream habitat assessment score ≥ 0.5 and a stream stressor score ≥ 0.6. These conservative minimum values represent a buffer system with at least 10 surviving trees per measured plot (a randomly selected sub-set of the buffer) and less than 20% invasive vegetation cover with stressor scores and stream habitat assessment at the lower end of the sub-optimal range. Under this scenario, CREP buffer systems receiving final SWR ecological condition scores below sub-optimal (Tier 2) would decrease in Maryland from 15% to 3%, in Pennsylvania from 15% to 5%, and in Virginia from 3% to 0%.

In the second scenario, assume a buffer system with mature trees, continued high tree survival rates and low invasive vegetation cover would receive the same minimum ecological condition metric scores as above except for improvements in minimum buffer score (≥ 0.5), minimum floodplain-wetland stressor score(≥ 0.75), and a stream habitat assessment scores (≥ 0.6). These conservative minimum values represent a similar system as above, except for mature trees now replacing saplings. Under this scenario (Figure 16), CREP buffer systems receiving final SWR ecological condition scores below sub-optimal (Tier 2) in Maryland and Virginia would be eliminated, and Pennsylvania would see a decrease in sites receiving these scores from 15% to 3%.

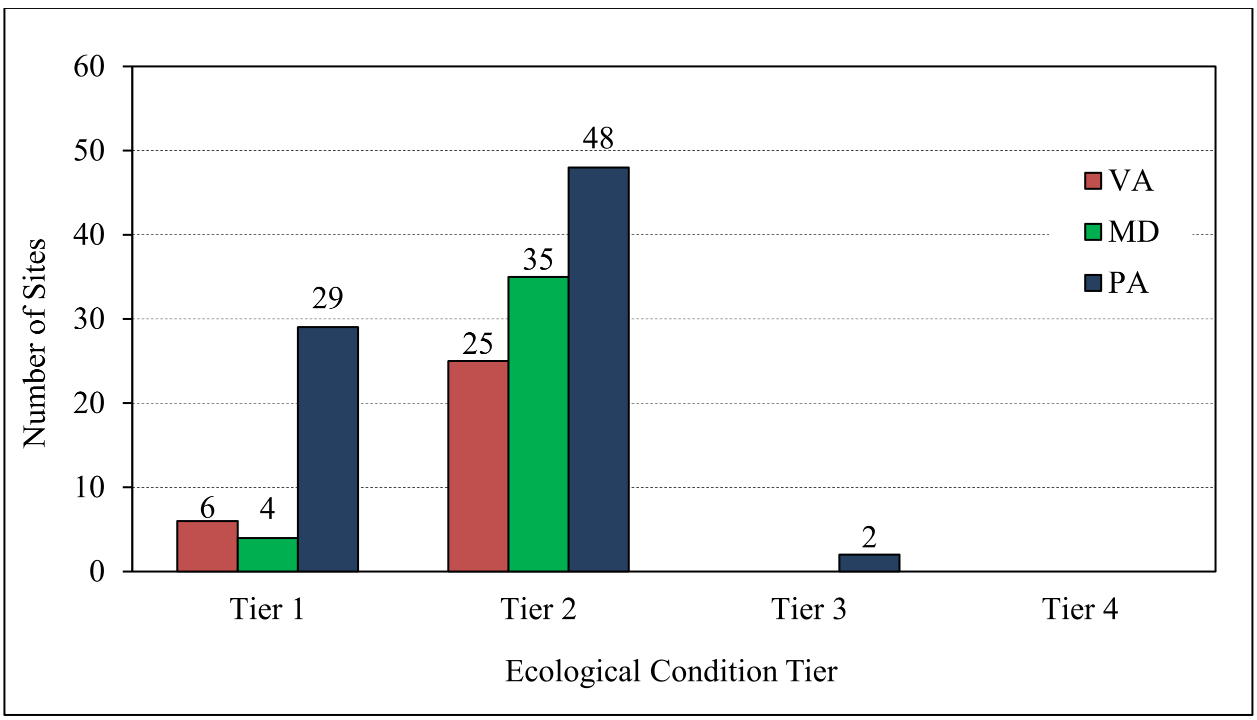


Figure 16: SWR Scores for Mature Forested Buffer Scenario

Soil sampling of CREP buffers across the Chesapeake Bay watershed points to a significant potential for legacy P in buffer soils to enrich runoff from buffers, undermining their benefits in mitigating P loss from agriculture. Soil P concentrations of CREP buffers ranged widely, reflecting the history of site use. Without mechanisms to remove P from buffer soils, P is essentially cycled in place, and there is little anticipated change in soil P status with buffer establishment and maturation. Across the three states surveyed, Maryland buffer soils were notable in their very high average P concentrations (expressed here as Mehlich-3 P, a common agronomic metric). However, averages for Pennsylvania and Virginia are also elevated. Assuming < 10 mg/kg represents a native Mehlich-3 P concentration, these soils are likely comparable to local agricultural soils and will support dissolved P concentrations in runoff comparable to those measured from agricultural fields.

Maryland CREP buffer soils averaged 88 mg/kg, roughly twice the concentration required for crop production (Figure 17). Many of Maryland's CREP buffers are located on the Delmarva Peninsula, a center of intensive poultry production with high rates of manure (litter) application. Based upon empirical relationships between Mehlich-3 P and dissolved P in surface runoff (Vadas et al., 2005), it is reasonable to project that CREP buffer soils are capable of dissolved P concentrations in runoff/drainage water of 0.3-0.5 mg/L (0.002 is frequently cited as a eutrophication threshold for freshwaters). With a good phytomining program (removing soil P by promoting biomass growth with other fertilizer nutrients and harvesting the biomass to export P), the average Maryland buffer soil could be expected to return to native levels in 10-20 years (Fiorellino et al., 2017). For the lower average soil P concentrations of other states, five years of concerted phytomining activity should be sufficient (Schelfhout et al., 2019).

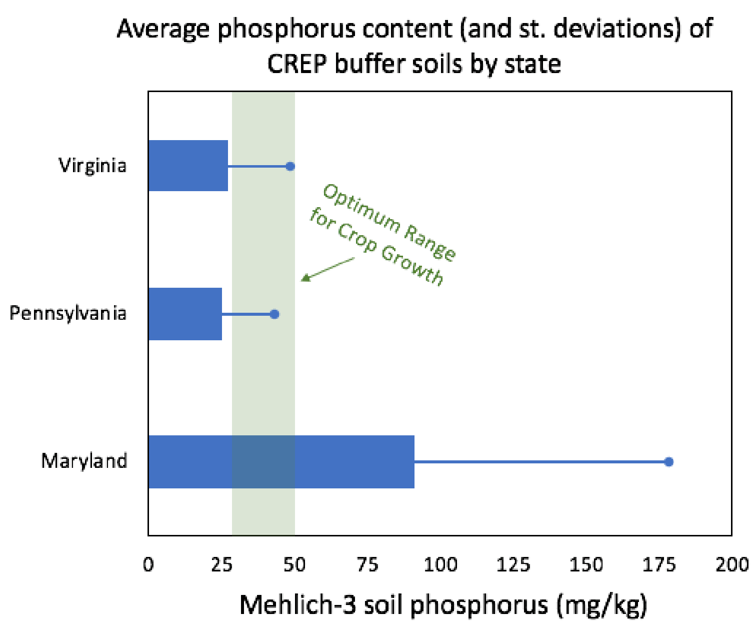


Figure 17. Variations in forested riparian buffer soil P levels, by state.

Hydrologic Routing from Contributing Areas through Buffers

Mitigation by riparian buffers of the sediment and nutrients being transported in flow through the buffer depends strongly on the transporting characteristic of that flow. As concentrated flow pathways develop within the buffers, water typically moves more quickly, which allows less settling of particles, and channelizes into deeper, narrower routes, which allows less opportunity for vegetation and above-ground roots to catch and filter the passing water.

We focused on contributing areas into CP22 buffers within four CEAP/LTAR watersheds that capture both high- and low- relief landscape features. Through hydrologic flowpath analysis, we then evaluated the role of concentrated flow pathways and artificial drainage features in bypassing filtration capacity of buffer soils. The occurrence of ditches and concentrated flowpaths reduced the total effective contributing area to the CP22 riparian buffers by approximately 78%, 22% and 38% in the Choptank, Conewago Creek and Mahantango Creek watersheds, respectively, Table 8. Spring Creek, a karstic watershed in the Ridge and Valley physiographic province, contained 3 CP22 sites, all of which fully treated their potential contributing areas.

Table 8. Assessment of flowpaths within CP22 buffer contributing drainage areas.

CEAP/LTAR Watersheds	Tuckahoe	Spring Creek	Conewago	Mahantango
Number of riparian buffers (CP22) assessed	11	33	13	25
CP22 buffers affected by concentrated flowpaths	7	--	7	11
Total potential (topographic) contributing area (acres)	638	214	1,592	1,206
Total effective contributing area (acres)	140	214	990	942
Percent treated by CP22	22%	100%	62%	78%

Micro-ditches were the main bypass features found in the Choptank watershed, Maryland. And as illustrated in figure 18, the presence of concentrated flowpaths and ditches can significantly impact the contributing drainage areas for riparian buffers.

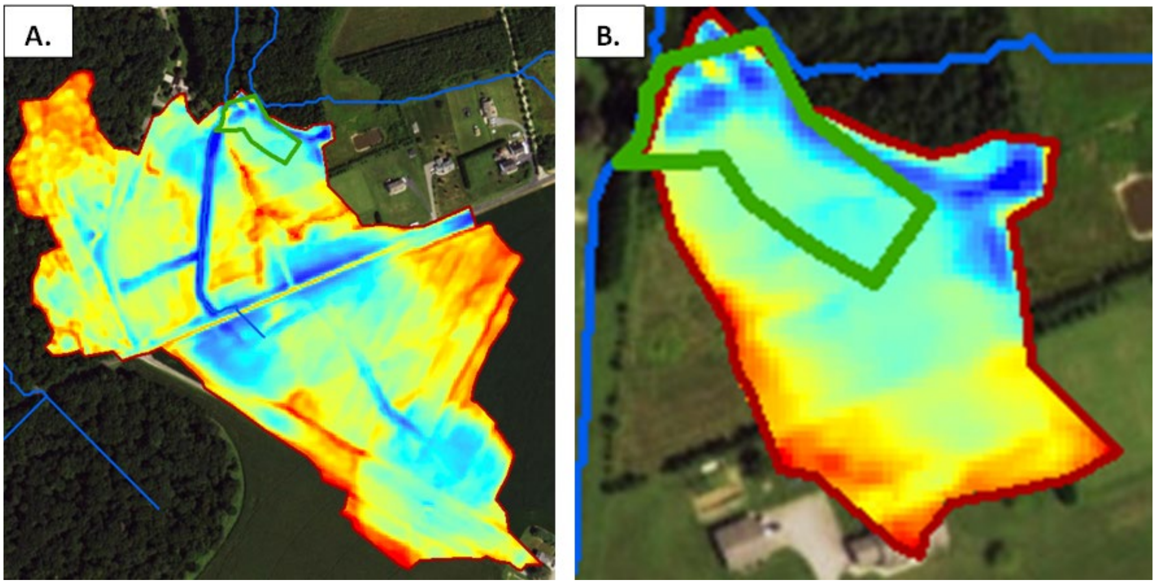


Figure 18. Topographic Openness for CP22 in Choptank watershed: potential contributing area (A.) of approximately 72 acres (29 ha) intersected by ditches that limit the buffer effective contributing area (B.) to 5 acres (2 ha), only 15% of the potential contributing area.

Convergent flows resulted in concentrated flowpaths, the dominant bypass feature in the high relief areas of the Pennsylvania (Conewago Creek, Mohantango Creek and Spring Creek watersheds) (Figure 19).

Figure 19. Flow Accumulation for CP22 contributing drainage areas in the Mahantango Creek watershed: (A. two concentrated flowpaths that fully transect the buffer, with the largest flowpath draining approximately 59% of the contributing area, and (B. one major concentrated flowpath where grassed waterway is implemented along with CP22 to maximize efficiency.

Under divergent flow conditions, multiple concentrated flowpaths or sheet flow disperse surface runoff across the entire buffer, thus increasing the ability of the buffer to effectively filter runoff, as shown in figure 20.

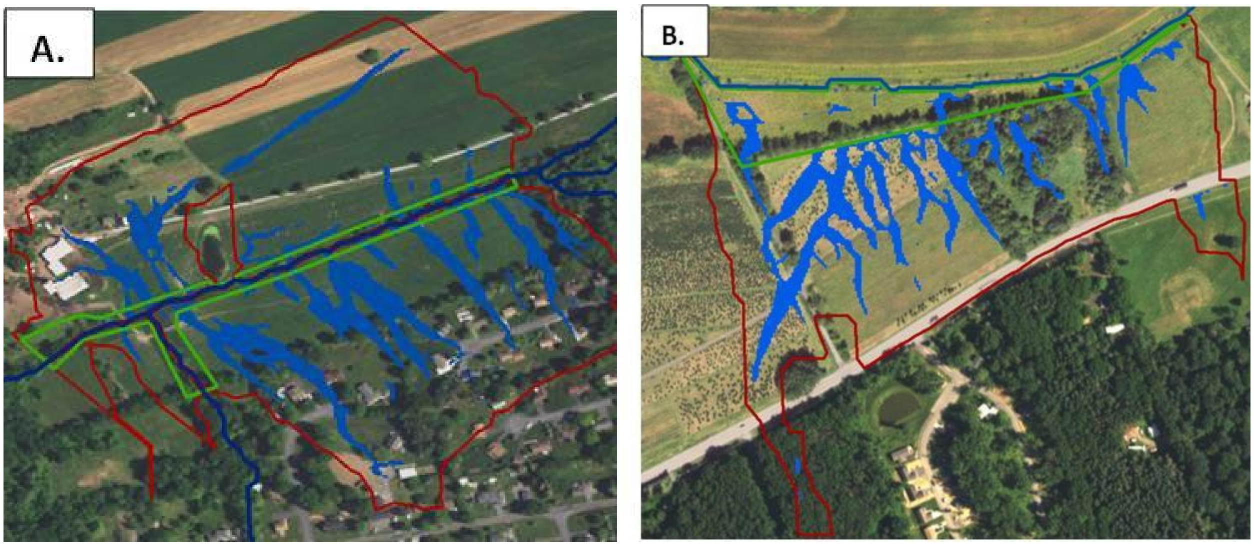


Figure 20. Flow Accumulation for CP22 contributing drainage areas in the Conewago Creek (A.) and Spring Creek (B.) watersheds.

Our modeling predictions currently estimate that total effective contributing area of riparian buffers is reduced 22-78%. In low-relief landscapes such as the Maryland Coastal Plain, micro-ditches are prevalent and bypass buffers, causing a corresponding bypass in the nutrient filtration of the buffer. However, synergistic activities of combining CP22 with CP21 and other practices can help mitigate some of these effects.

Water Quality Modeling of CREP Buffers

30-m Buffer Zone Results:

Stream network density is similar among all three high relief watersheds (Figure 21), resulting in a total buffer area that is 2-4% of the total watershed area (Table 9). Spring Creek has the most area in development and Conewago has the least area in row crops, but otherwise land use within the buffer areas of Spring Creek and Conewago are similar. Mahantango and Spring Creek have nearly the same total watershed area and buffer area, but Spring Creek has 33% of the riparian area developed whereas Mahantango has only 7% developed. Also, although Mahantango has only 17% of the land in agriculture, as compared to 25% buffer land in agriculture in Spring Creek and Conewago, a much larger portion of that land is in row crop than in hay. In fact, in any given year, both Spring Creek and Mahantango have about 160 ha of row cropped land within the 30-m riparian buffer in the baseline scenario.

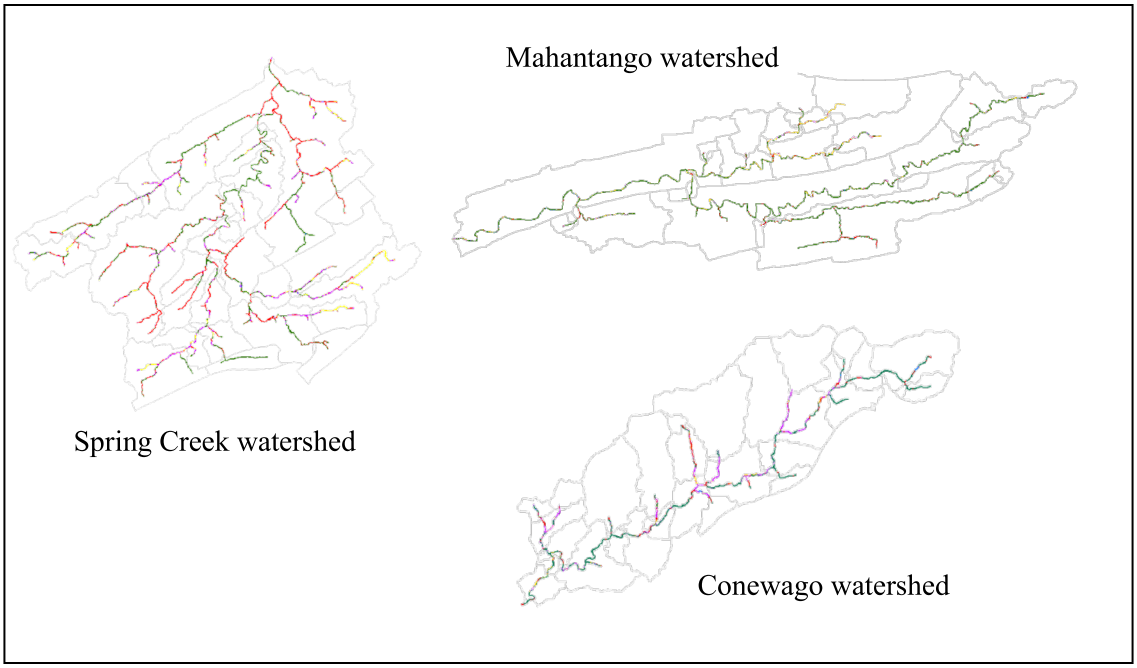


Figure 21. Major subbasin boundaries and GIS-buffered stream network, as represented in Topo-SWAT.

Table 9. Existing land use in the 30-m GIS buffer zone of the high relief watersheds.

	Spring Creek		**Conewago**		**Mahantango**	
	ha	**% area**[1]	ha	**% area**[1]	ha	**% area**[1]
Total watershed area	36869		13580		41920	
Buffer strip area	1355	**4**	370	**3**	1031	**2**
Agriculture (row crops + hay)	338	**25**	90	**24**	174	**17**
Row crops	*160*	***12***	*42*	***11***	*157*	***15***
Hay	*178*	***13***	*48*	***13***	*17*	***2***
Forested	558	**41**	200	**54**	767	**74**
Developed	452	**33**	48	**13**	75	**7**

[1] Within buffer, this is % of buffer area. For the buffer area itself, this is % of total watershed area.

Relatively larger amounts of N were lost from Spring Creek than from Conewago (Table 10). This was as expected due to the karst hydrology and increased development of Spring Creek. In contrast, the more hilly and rural watershed of Mahantango contributed relatively larger amounts of sediment. Overall, Mahantango loads were 10x those of each of the other 2 watersheds. This was likely due to the relatively large proportion of row cropped buffer area in Mahantango.

Table 10. Total average annual loads of nutrient and sediment from each watershed for different scenarios.

Scenario	Total N (kg/year)	Total P (kg/year)	Total Sediment (kg/year)
Spring Creek Watershed			
Baseline	460250	65720	18344380
Grass buffer	453913	64384	18236880
Forest buffer	453463	64299	18230750
Conewago Watershed			
Baseline	192763	45551	7116125
Grass buffer	191325	45139	7116000
Forest buffer	191163	45095	7115875
Mahantango Watershed			
Baseline	1610170	529810	33225000
Grass buffer	1601600	526700	33218000
Forest buffer	1600460	526410	33218000

Among all watersheds, forest buffers were slightly more effective than grass buffers at reducing both N and P (Table 11). As compared to non-buffered land, buffers reduced about 4 times more N than P in kg/ha/yr among all watersheds. Reduction in sediment varied substantially among watersheds.

Table 11. Average annual effectiveness (kg load reduction per ha of agricultural buffer) of the grass and forest buffer scenarios in controlling nutrient and sediment losses.

Scenario	Total N (kg/ha/year)	Total P (kg/ha/year)	Total Sediment (kg/ha/year)
Spring Creek Watershed			
Grass buffer	18.75	3.95	318
Forest buffer	20.08	4.20	336
Conewago Watershed			
Grass buffer	15.97	4.58	1.39
Forest buffer	17.78	5.07	2.78
Mahantango Watershed			
Grass buffer	49.25	17.87	40.23
Forest buffer	55.80	19.54	40.23

The change in land management from cropland to mature forest within the 30-m GIS buffer zone (a rough estimation of the existing CP22 area) clearly results in less phosphorus and nitrogen loading from the buffer zone, as expected (Figures 22 and 23, respectively). However, in situations where the total and the effective contributing area (from objective 1.1) are identical, such as is the case in this Spring Creek example, nitrogen loading the scenario change does not impact the nutrient losses upslope of the buffer zone.

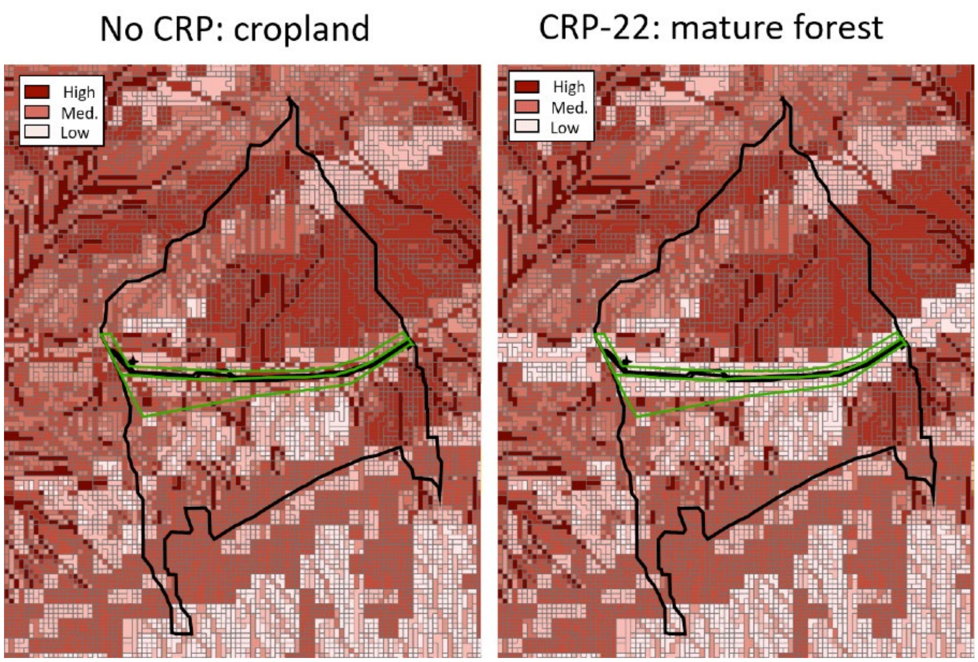


Figure 22. Losses of total phosphorus to the stream through a 30-m GIS buffer zone corresponding to an existing CP22 site within the Spring Creek watershed.

At a local scale, total phosphorus loadings to the stream within the CP22 total contributing area, as defined in objective 1.1, are the largest along the most prominent flow paths (Figure 22). As a result, the highest phosphorus loadings into the northern edge of the stream in Figure 22 come from the region of concentrated flow. In contrast, phosphorus loadings into the southern bank of the stream are contributed more uniformly across the upslope length of the stream reach.

Total nitrogen loadings to the stream through the buffer zones to the stream are not tied as closely to well-defined flow paths as phosphorus (Figure 23). This further supports the idea that phosphorus, of which a majority is typically sediment-bound, will require more flow before being transported to the stream than will the nitrogen which is largely soluble. In areas of more uniform and less concentrated flow, nitrogen loadings tend to be low as nitrogen has had a chance to leach into the soil profile.

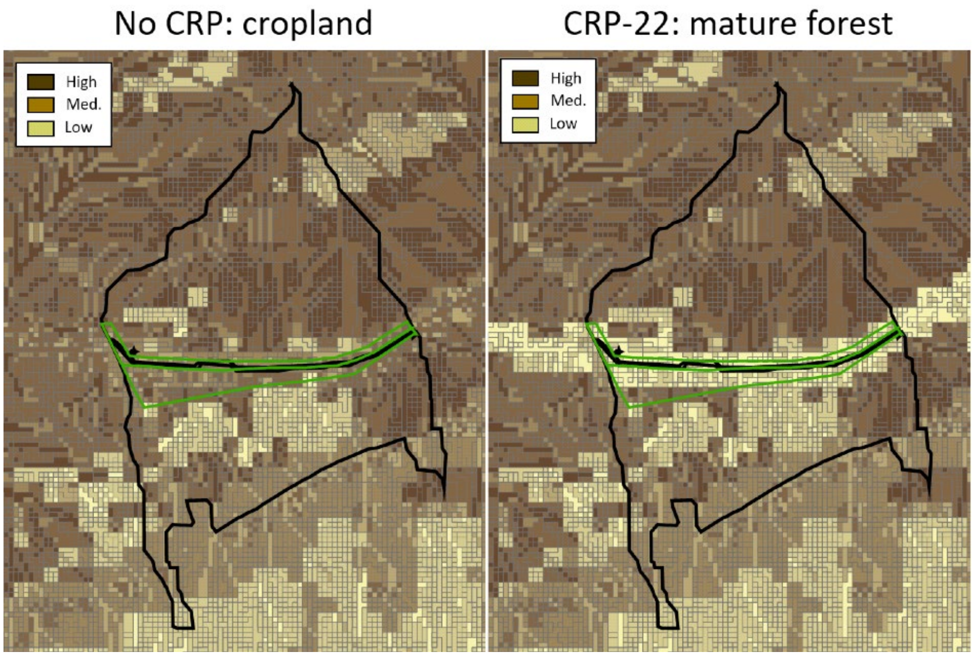


Figure 23. Losses of total nitrogen to the stream through a 30-m GIS buffer zone corresponding to an existing CP22 site within the Spring Creek watershed.

CP22 simulated results:

The impact of the existing CP22 areas combined across the watershed was quantified for each watershed. In Conewago, the combined area of the effective contributing areas, as defined in objective 1.1, was 38% less than the combined area of the total contributing areas. The total phosphorus and nitrogen loadings to the stream for the effective contributing areas were estimated by the Topo-SWAT scenarios to be 40% and 43%, respectively, of the loadings from the total contributing areas. In other words, roughly 40% of the nutrients from the total contributing area are bypassing the CP22 buffer and not being mitigated by this control practice.

Understanding effectiveness of CP buffers requires both modeling of nutrient losses and fine-scale flow path analysis. More varied watersheds are likely to impact TN and TP differently. The Conewago watershed, in the Piedmont province, is fairly homogenous with regard to distribution of agricultural areas and topography. The Spring Creek watershed, in the karst portion of the Ridge and Valley province, has steeply sloping forested headwaters but the agricultural valleys are of low relief with depressions and sinkholes. These features minimize the accumulation of surface flow into concentrated flowpaths reaching buffered streams. The Mahantango, in the non-karst portion of the Ridge and Valley, has steeply sloped hill which are prone to concentrated flow paths and bypass features if not mitigated both within the field and the buffer.

In the Tuckahoe watershed, riparian buffers were effective at reducing organic N loads with reduction efficiency of ~ 45%. The reduction efficiency increased with the increasing extent of riparian buffer implementation. The reduction efficiency varied both seasonally and temporally for this region. Reduction efficiency tended to be high during early spring seasons due to an increased possibility of surface runoff plus higher N loads in the soil water. The reduction efficiency was more notable in croplands than other land use types likely due to nutrient increased soil N supply from fertilizer.

Ecosystem Services

Expected changes in ecosystem services were evaluated for **carbon storage, floodwater storage, biodiversity, water purification,** and **water-based recreation**. Most of the benefits from the suite of services considered were described in narrative or semi-quantitative ecological terms. Methods for each included in the appropriate section.

Assessments presented within the subsamples of the CREP project in PA provide examples of comparisons of ecosystem service outcomes based on: 1) current CREP standards, 2) optimized management, and 3) optimized CREP buffer placement using targeted buffer placement recommendations using the AgBufferBuilder program.

Results from the PaCT tool investigations present interesting findings and opportunities for enhancing a multitude of ecosystem services. A blank Excel spreadsheet for the PaCT process is provided as a separate file for entering buffer values for a wide range of provisional, regulating, and supporting services. A sample of the PaCT tool layout is shown in a screenshot in Appendix C. The examples below represent PaCT scores for corresponding scale in relation to top of bank assessments, and various management implications on said services. The ecosystem service scores represented under CREP describe the currently installed CREP buffer and current management strategies within and outside of the contracted buffer. Within example Site #49, results (Figure 24) represent that current practices within the CREP contracted buffer are fairly high (Regulating 1.04; Supporting 5.69) except for provisioning services (0.48) which is low due to removal of agricultural production. When using PaCT at greater scales beyond the implemented buffer, diminished regulating and supporting services are represented due to the allocation of percent area of land influenced by current agricultural impacts as well as increased influences on concentrated by-pass flows undermining buffer efficacy. Hence, negative scores for both regulating (-0.57) and supporting services (-1.23), while increases in provisioning services (2.27) are justified.

An interesting feature of the PaCT tool is that a multitude of management scenarios can be quantified and compared. In this example, an idealized suite of management practices where developed, focusing on differences in management within concentrated by-pass flows and non-critical areas of agricultural runoff. PaCT results are shown in Figure 25a representing a scenario in which a CP22 is implemented as a variable width buffer recommended using AgBufferBuilder. For site #49, AgBufferBuilder determined the current CP22 was achieving 86% of sediment trapping efficiency, however, only 35% of the implemented buffer accounts for 75% of the sediment trapping efficiency. When considering the potential to enhance ecosystem services across all categories, the majority of the buffer may be allocated to alternative management strategies. In this case, additional best management practices were applied outside of these concentrated pathways during the PaCT run to determine whether higher provisioning scores can be achieved without loss to regulating and supporting services. Within this scenario, significant increases in all ecosystem service categories and within all scales as shown in Figure 25b, thus showing that alternatives to a one-size fits all buffer standard may be reducing potential for landscape ecosystem services, especially when landscape scale is considered.

While the tools does not quantify actual ecosystem services across a landscape, the variability in the PaCT aggregated scores help to determine when more services within a category are enhanced or reduced due to the variable options of management applied to the ecosystem. Thus, the PaCT tool in these examples represented during the field visits during this project, elucidates opportunities for improvements in targeting CP22 placement, but also for suites and combinations of additional best management practices that can enhance conservation outcome goals and producer demands within the same ecosystem.

Site Id #49: PaCT Score: Riparian Buffer

System	Provisioning Service	Regulating Services	Supporting Services	PaCT Score
CREP	0.48	1.04	5.69	7.22
Managed	1.89	6.07	7.99	15.95

Site Id #49: PaCT Score: 100m Zone

System	Provisioning Service	Regulating Services	Supporting Services	PaCT Score
CREP	1.91	0.2	2.24	4.15
Managed	3.01	4.82	4.48	12.31

Site Id #49: PaCT Score: Contributing Area

System	Provisioning Service	Regulating Services	Supporting Services	PaCT Score
CREP	2.27	-0.57	-1.23	0.47
Managed	3.05	4.39	2.36	9.92

Figure 24. Scores for ecosystem services increase for simulated management scenarios on an actual CREP riparian buffer, and in the surrounding landscape.

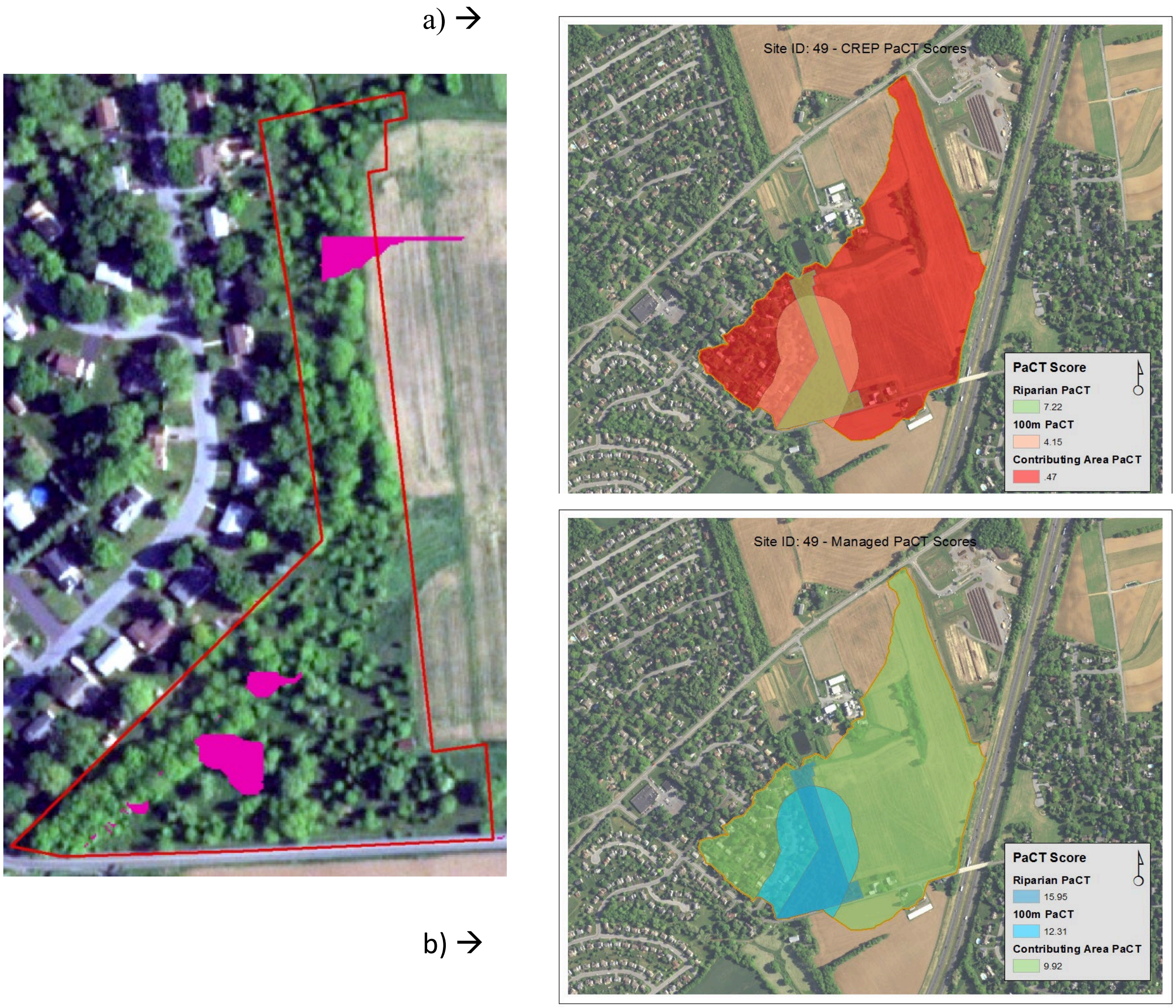


Figure 25. Hydrologic short-circuiting in actual riparian buffer (left image): a) current scores before simulated management scenario applied; b) scores improved after management was applied outside the buffer area, at a 100-m width and in the hydrologic contributing area.

CARBON STORAGE:

Findings from exploring the carbon storage ecosystem service show that three pools hold the majority of carbon – soil, above-ground woody, below-ground (roots). Estimation of carbon pool measurements followed Mazurczyk and Brooks (2018), which was developed on wetland and riverine reference sites in the same geographic region. These sites span the 3 ecoregions featured in this riparian buffer assessment. In addition, results for riparian buffers assessed with the SWR Index showed that CREP buffers performed at least as well as ASC natural buffers. We aligned carbon values with expected vegetation (successional stage) and soil (degree of wetness) conditions found at sample sites throughout each watershed based on variables obtained from Level 1 Landscape Analysis and Level 2 SWR Index. It is important to note here that the field sites investigated for this project were recently installed riparian forest buffers (the most established being about 15 years old), thus, they would not be expected to store carbon in the same quantities similar as mature riverine reference wetlands or natural riparian buffers with mature forest cover (Figures 26 and 27). Using riparian forest buffers and other BMPs to create and maintain healthy riparian ecosystems with maturing forests and soils with substantial carbon content will enhance the carbon storage and sequestration benefits of these conservation practices in agricultural landscapes.

Site ID	Total Carbon (tonnes/ha)	Reference Site #	Total Carbon (tonnes/ha)
SP-03	326.80	3	85.16
SP-04	62.47	5	165.55
SP-05	95.54	18	76.75
SP-06	181.03	26	64.56
SP-09	65.29	28	72.28
SP-17	340.70	30	173.94
SP-22	301.08	31	100.71
SP-25	102.21	32	125.34
SP-26	44.23	33	254.62
SP-27	299.02	53	47.65
SP-33	327.66	57	140.07
SP-36	62.75	64	66.85
SP-38	275.18	70	233.41
SP-42	538.76	71	68.60
SP-46	96.87	162	275.55
SP-47	260.12		
SP-50	263.63		

Carbon Storage

CNS Riparian Sites
vs.
Penn State Riparia
Reference
Wetlands

(for Spring Creek)

Frequency Distribution

Frequency Class (Quartiles)	CNS Sites	Reference Sites
0-25%	66.05	61.92
25-50%	126.71	92.05
50-75%	279.81	152.81
75-100%	383.48	234.38

Figure 26. Carbon storage in metric tonnes/ha for CNS riparian sites in Spring Creek watershed vs. reference wetlands in similar riverine settings from Riparia's past studies. CNS riparian sites had higher carbon storage than similar reference sites, and were comparable to CREP buffer sites.

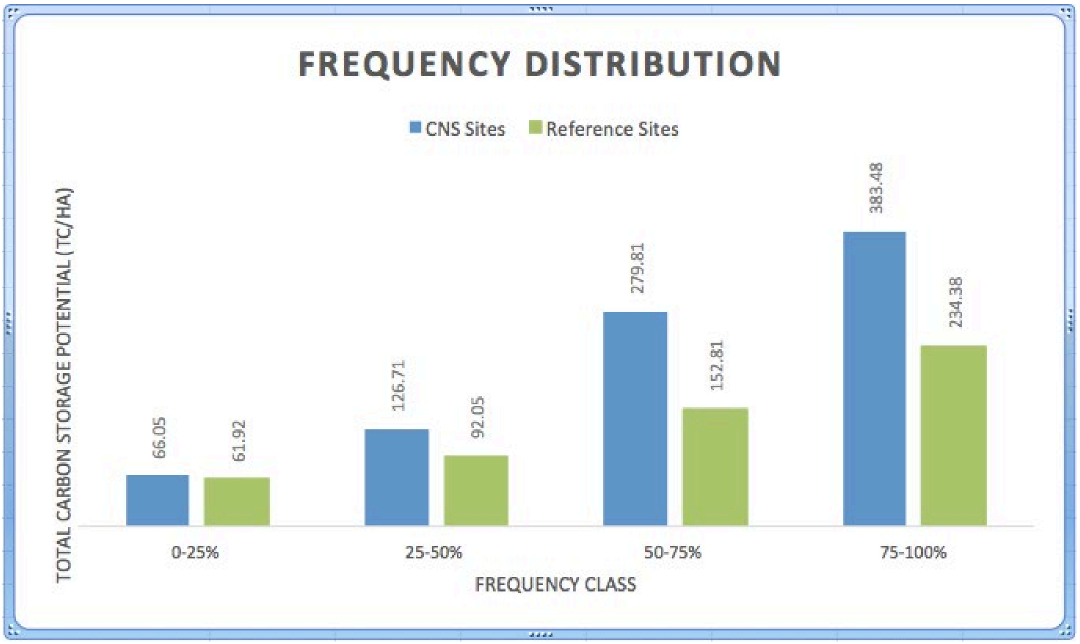


Figure 27. Carbon storage in metric tonnes/ha in quartiles for all CNS riparian sites vs. reference wetlands from Riparia's past studies.

FLOODWATER STORAGE:

A draft Flood Storage Index was developed based on available data from a parallel study (Center for Nutrient Solutions (CNS), Shortle et al. 2019) as a way to estimate the relative level of service among riparian sites. Some of the CREP sampled riparian buffers occurred in the Mahantango Creek watershed of east-central Pennsylvania, within the Susquehanna-Chesapeake Watershed. Following the logic of Yetter (2013) for northern temperate streams in Pennsylvania, we assume that flood storage is a function of: 1) *reach confinement* (a function of topography), 2) *riparian complexity* (presence or absence of microhabitats), 3) *connectivity* (capacity for two-way flows between stream channel and the floodplain), 4) *riparian vegetation* (type and extent of vegetated banks and floodplains; higher stem density and larger stem size are preferred for retaining floodwaters), and 5) *anthropogenic stressors* (e.g., observed or inferred stressors that negatively alter the riparian corridor.

Floodwater storage occurs either when there is overbank flooding that inundates the floodplain (*flood pulse*) or when lower elevation portions of the floodplain (active zones) are inundated by below bankfull events (*flood flows*). The presence of multiple habitat types, many connected to outlets below bankfull elevations, promotes greater flood storage. In addition, wider buffers with greater and larger stem densities will slow flows and increase retention times. By examining these characteristics of the riparian corridor, we believe one can infer the degree of flooding across four categories – optimal, suboptimal, marginal, or poor.

Thus, we examined indicators in our available datasets to represent the range of hydrogeomorphic and biological conditions found with the riparian corridor.

1) *reach confinement* – use either a topographic layer or LIDAR based DEMS to classify

SWR point as unconstrained or constrained reach, the latter offering scant space for floodwater storage.

2) *riparian complexity* – the presence or absence of microhabitats that collectively form headwater for floodplain complexes, which can include riffles, pools, seasonal and temporary depressions, slope wetlands discharging groundwater, or abandoned (paleo-) stream channels; discerned from SWR sketch map, aerial photographs, or other means; a score of </= 10 on SHA Item #6 – Channel Alteration, implies low complexity and poor connectivity.
3) *connectivity* – in addition for the features mentioned in 1) and 2), the stream channel must remain hydrologically connected to the floodplain; a high incision ratio means that flood frequencies are less because the channel has been cut downward reducing opportunities to flood; measured by incision ratio for SWR reach; a score of </= 10 on SHA Item #8 – Bank Stability, implies poor bank stability either from excessive flows causing erosion and/or incision, or intensive access by livestock (should be observed from stressor checklist).
4) *riparian vegetation* – a narrow riparian corridor with minimal vegetation reduces retention time of floodwaters, plus higher and larger stem densities in the floodplain slow flows and prolong storage; scores of </= 10 for SHA Items #9 - Vegetative Protection & #10 – Riparian Vegetative Zone Width imply lower floodwater storage potential.
5) *anthropogenic stressors* – observed stressors in either portion of the riparian corridor may indicate inhibition to floodwater storage; examine type and number of stressors and compare to reference standard scores.

The results for each unconstrained monitoring riparian reach for Mahantango Creek are shown in Figure 28. MH01 and MH04 are in the WE38 subwatershed; MH21 is at the outlet or weir for WE38; MH14 and MH24 are small unnamed tributaries to Mahantango Creek, MH16 and MH17 are on Little Mahantango; MH25 and MH26 are on Deep Creek. The change in Floodplain Index Scores across different buffer cover types is shown in Figure 28. Streams flowing through extensive mature forest buffers provide much higher flood water retention and carbon storage services than streams with only grass or no buffers.

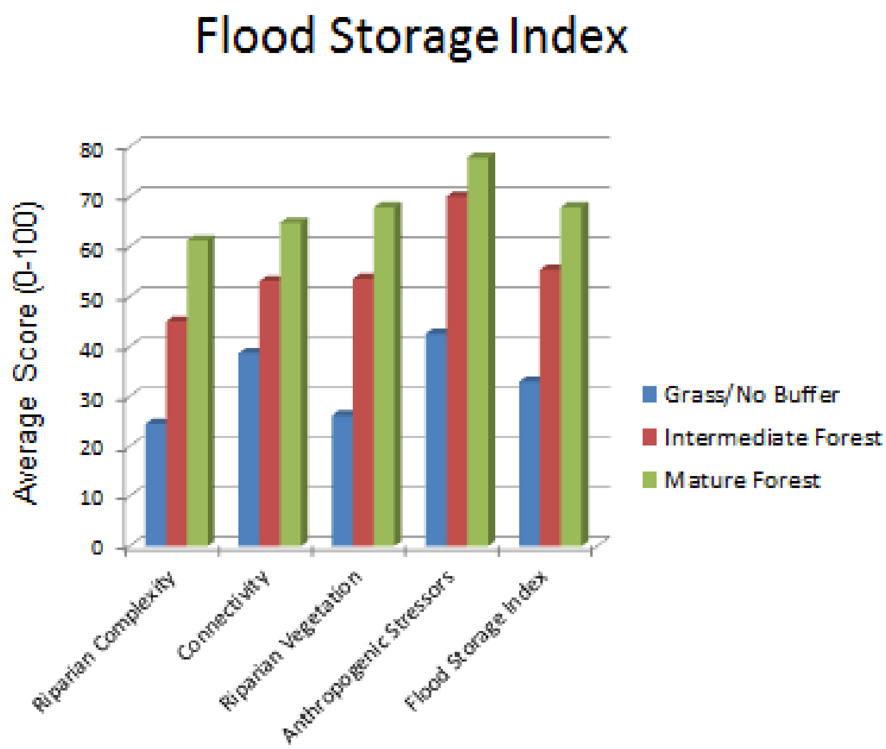


Figure 28. Flood Storage Index scores for riverine complexes in the Mahantango Creek watershed across different buffer types.

WATER RECREATION (FISHING), PLUS BIODIVERSITY & WATER PURIFICATION:

State waters are protected for a *designated aquatic life use* as well as a number of water supply and recreational uses. The use designation shown in the water quality standards is the aquatic life use (terms used are for Pennsylvania, but are similar in other states). These uses are Warm Water Fishes (WWF), Trout Stocking (TSF), Cold Water Fishes (CWF), and Migratory Fishes (MF). In addition, streams with excellent water quality may be designated High Quality Waters (HQ) or Exceptional Value Waters (EV). The water quality in an HQ stream can be lowered only if a discharge is the result of necessary social or economic development, the water quality criteria are met, and all existing uses of the stream are protected. EV waters are to be protected at their existing water quality; water quality shall not be lowered.

We attributed recreational fishing to a waterbody's ability to support fish and other aquatic life (i.e., its aquatic life use or ALU), which is defined by water quality standards. This approach necessarily overlaps with biodiversity and water purification services. Using data and results from a parallel study (Center for Nutrient Solutions (CNS), Shortle et al. 2019) we followed Pennsylvania's protocols for biological monitoring of surface waters as indicated by macroinvertebrates (i.e., Indexes of Biotic Integrity or IBIs) to assess attainment status of the monitoring sites that occurred in Long-Term Agricultural Research (LTAR) watersheds where riparian buffers were studied. HQ waters exceed water quality standards and support high quality aquatic communities and may include Class A wild trout streams. EV waters, as their name signifies, are of the highest quality, which may be defined by several factors, including exceptional ecological significance or wilderness trout stream (Figure 29).

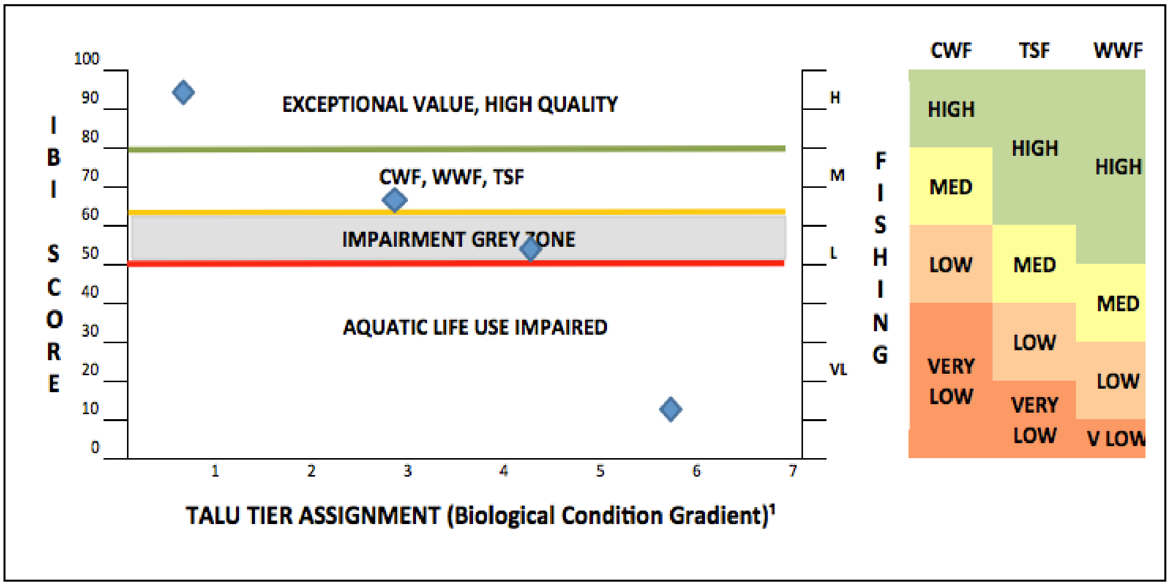


Figure 29. Macroinvertebrate IBI as indicator of recreational fishing (CWF= Cold Water Fishes, TSF=Trout Stocking Fishes, WWF=Warm Water Fishes) from Center for Nutrient Solutions Project (i.e., Shortle et al. 2019).

- Trout fisherman—need CWF and HQ/EV waters will provide best recreational experience. CWF streams with high IBI scores are the most likely candidates for brook trout. Medium yellow area would probably still be good for brown trout.
- Largemouth bass fisherman—larger range of IBI scores for WWF.

Outreach, Webinars, Buffer Tours

During the period July 2017-May 2018 efforts were focused on evaluating the effect of concentrated flowpaths on the riparian forest (CP22) buffers' ability to reduce sediment, nitrogen and phosphorus losses, because we determined this issue was of major concern and needed attention during maintenance activities. Additionally, we evaluated synergies between CP22 and other conservation practices including riparian grass (CP21) buffers and grassed waterways and the water bypass on riparian buffers.

We conducted webinars and buffer tours (tied to each of the three states involved). Extensive conference calls and meetings were held in the latter half of the project to strategically focus attention on reaching out to all levels in the pertinent agencies – headquarters, state, and county – to insure their participation in webinars, buffer tours, and in providing feedback based on their experiences with planning and implementing riparian forest buffers in their respective states.

These outreach efforts were successful in that we were able to involve USDA at all levels, along with selected partner agencies, practitioners, and buffer landowners, to communicate findings, and gather input and recommendations from participants (see Appendix A). About 50 agency representatives, practitioners, and landowners attended each of the Buffer Tours. Lunch meetings were held for several hours after each tour, which generated many useful discussions and specific recommendations about enhancing the CREP Riparian Forested Buffer program, including the integration of buffers with other conservation practices.

Geographic areas featured during Buffer Tours and accompanying Webinars (see Appendix A)

- 12 October 2017 – Central Pennsylvania Piedmont, near Lancaster, PA
- 21 February 2018 – Maryland Coastal Plain, near Denton, MD
- 1 May 2018 – Virginia Ridge and Valley, near Harrisonburg, VA

A series of four webinars to assess CP22 (forest buffers) effectiveness across PA, MD, and VA introduced important questions about buffer design, practices, and environmental benefits. Then, on-site Buffer Tours in each state examined several CP22 sites as a group to discuss what was working, what wasn't, and ideas for future design, implementation, and education.

List of Webinars conducted during 2017 and 2018:

- June 15, 2017: "Assessment of Riparian Forest Buffers within the Susquehanna-Chesapeake Watershed" (https://vimeo.com/223303822)

- October 10, 2018: "Understanding and applying lessons from CREP riparian forest buffers in Pennsylvania" (https://cc.readytalk.com/cc/playback/Playback.do?id=97eb60)

- February 20, 2018: "Understanding and applying lessons from CREP riparian forest buffers in Maryland" (https://youtu.be/gHtt0ZYEIjM)

- April 30, 2018: "Understanding and applying lessons from CREP riparian forest buffers in Virginia" (https://youtu.be/ADuC84BhQLU)

Additionally, on May 24, 2018 a webinar was conducted to summarize a related Chesapeake Bay Riparian Forest Survey: "Summarizing the Chesapeake Bay Watershed Riparian Forest Buffer Survey" Skip Hyberg (FSA), Don English (US Forest Service) and Rich Iovanna (FSA). (https://youtu.be/z7hETCv4qBY)

Project investigators took advantage of other conferences and opportunities to present preliminary and final results from this assessment of performance of riparian buffers. A listing of these event can be found after the Acknowledgments section. We are currently working on multiple scientific papers to publicize our findings in the peer-reviewed literature. Copies of these papers will be provided to the USDA Farm Service Agency and other interested parties when available.

Summary of Findings

Here are the key results were obtained from the assessment and performance of buffers during this study:

- Buffers provide a variety of ecosystem services. Enhanced water quality, the benefit most closely associated with buffers, is the principal objective of the Chesapeake Bay CREPs.
- This project identifies key factors in the design and management of CREP buffers that influence their effectiveness in improving water quality.
- Better understanding not only the site condition, but also the upslope and upstream conditions will enhance targeting of buffers thereby improving riparian management.
- The majority of CREP riparian forest buffers scored in the second highest category of condition assessment (sub-optimal), comparing favorably with natural riparian forest buffers.
- Runoff filtration by riparian buffers is often undermined by gullies and ditches that route runoff water around the buffer, suggesting that targeted maintenance of concentrated flow features is key to improving the buffer performance.
- Riparian areas with extensive mature forest buffers provide much higher retention of floodwaters and higher levels of carbon storage than streams with only grass or no buffers.
- Selected watersheds in the study area had a high density of riparian buffer project in proximity to each other (e.g., northern and central Virginia). We believe by emphasizing the clustering of conservation projects, particularly in headwaters areas, cumulative water quality and ecosystem service benefits can be acquired.
- CREP buffers balance CREP design requirements, landowner goals, surrounding land use impacts, and physical site constraints. This balance makes each site unique making the role of the person providing technical assistance critical for their successful design and implementation, yet there is turnover in staff and land ownership that challenges long-term maintenance.
- Practitioners reported ways to enhance the existing program through interagency/organization coordination, funding for longer-term maintenance, and opportunities for product and income generation within buffers.
- Landowners that self-farmed lands are more capable and more likely to do maintenance on buffers; whereas non-farming landowners need assistance, which could come from service providers and/or NGOs.
- Flexibility in buffer design, management, and maintenance can add value and appeal for a wider array of landowners. Allowances for sustainable removal of biomass and products (e.g., fruits, nuts, other plant products) should be considered.
- Offering suites of conservation practices to landowners can address multiple issues and increase values to participants.

Further Recommendations

Understanding the landscape processes and structural characteristics of riparian buffers is important to determine how well buffers are capable of functioning at a given location. And prioritizing the location of buffers in some areas rather than in others within a watershed offers significant benefits for water quality and control of surface runoff. Hence, size, variable buffer width, slope, upslope runoff area, and soil type among others are important factors to consider when designing effective buffers. In addition, monitoring practices are fundamental to make the necessary adjustments over time when maintaining buffers. As an overall characterization, most surveyed riparian forest buffers were installed parallel to streams functioning as traps of pollutants and soil particles transported in surface runoff. They were found to be similar to natural riparian buffers in the same region.

Project studies demonstrated that examining flow routing patterns across a landscape is essential for correct buffer placement and for assessing the effectiveness of CP22 buffers in mitigating the impact of surface runoff and associated pollutant loadings. The results developed in the project demonstrate the ability of two topographic metrics to analyze and visualize overland flow routing patterns, which is important for good environmental conservation planning. The feasibility of using either the topographic openness (Figure 30) or flow accumulation (Figure 31) method relies on the availability of high resolution DEMs and on topographic relief. High resolution DEMs derived from LiDAR data provide highly detailed representations of the landscape when matched up against aerial photography. The two topographic visualization techniques examined in this study agreed with each other 100% of the time for the 52 CP22 buffers in the Chesapeake Bay Watershed. However, the flow accumulation technique displayed concentrated flow paths best in medium to high and high relief areas such as those in the Piedmont and Appalachian Ridge and Valley physiographic provinces, when compared to topographic openness. The topographic openness on the other hand, worked best for displaying hydrologic features in low relief areas such as the Coastal Plain.

Results also indicated that hydrologic bypass features occurred in approximately half of the study sites (27 of 52) across all four watersheds. Hydrologic bypass features, whether drainage ditches or concentrated overland flows, were found to reduce the potential contributing areas to CP22 buffers by as much as 78%. Thus, the effectiveness of CP22 buffers to intercept and reduce pollutant loadings from surface runoff were reduced significantly. Surface water quality may suffer in areas with poorly designed and poorly placed buffers. Therefore, conservation managers should consider the occurrence of hydrologic bypass features when designing riparian buffers to protect stream water quality, and specifically develop maintenance programs to keep buffers functioning at the highest levels possible over time.

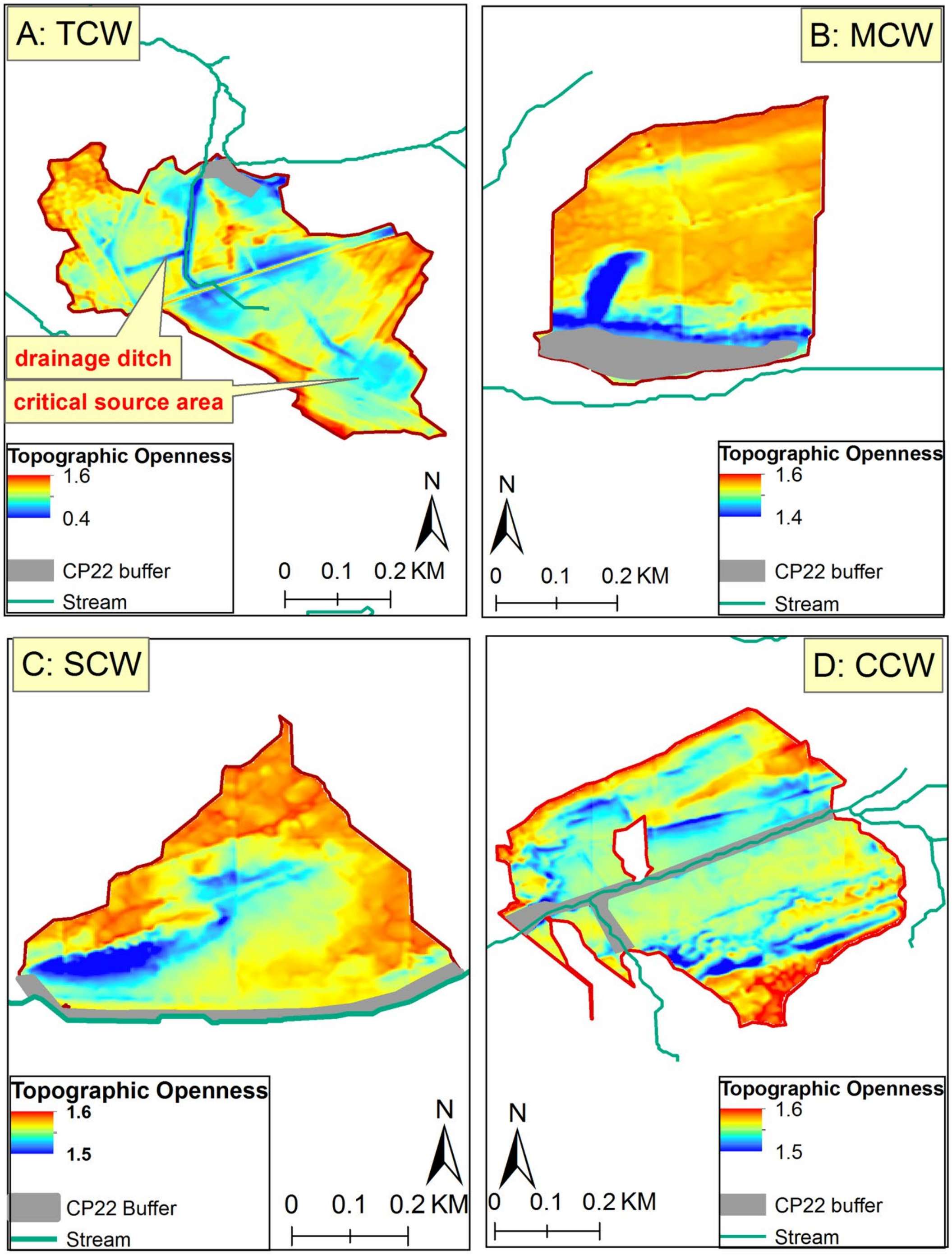


Figure 30. Map of topographic openness for riparian forest (CP22) buffers contributing areas in Tuckahoe Creek (TCW) [A], Mahantango Creek (MCW) [B], Spring Creek (SCW) [C] and Conewago Creek (CCW) [D].

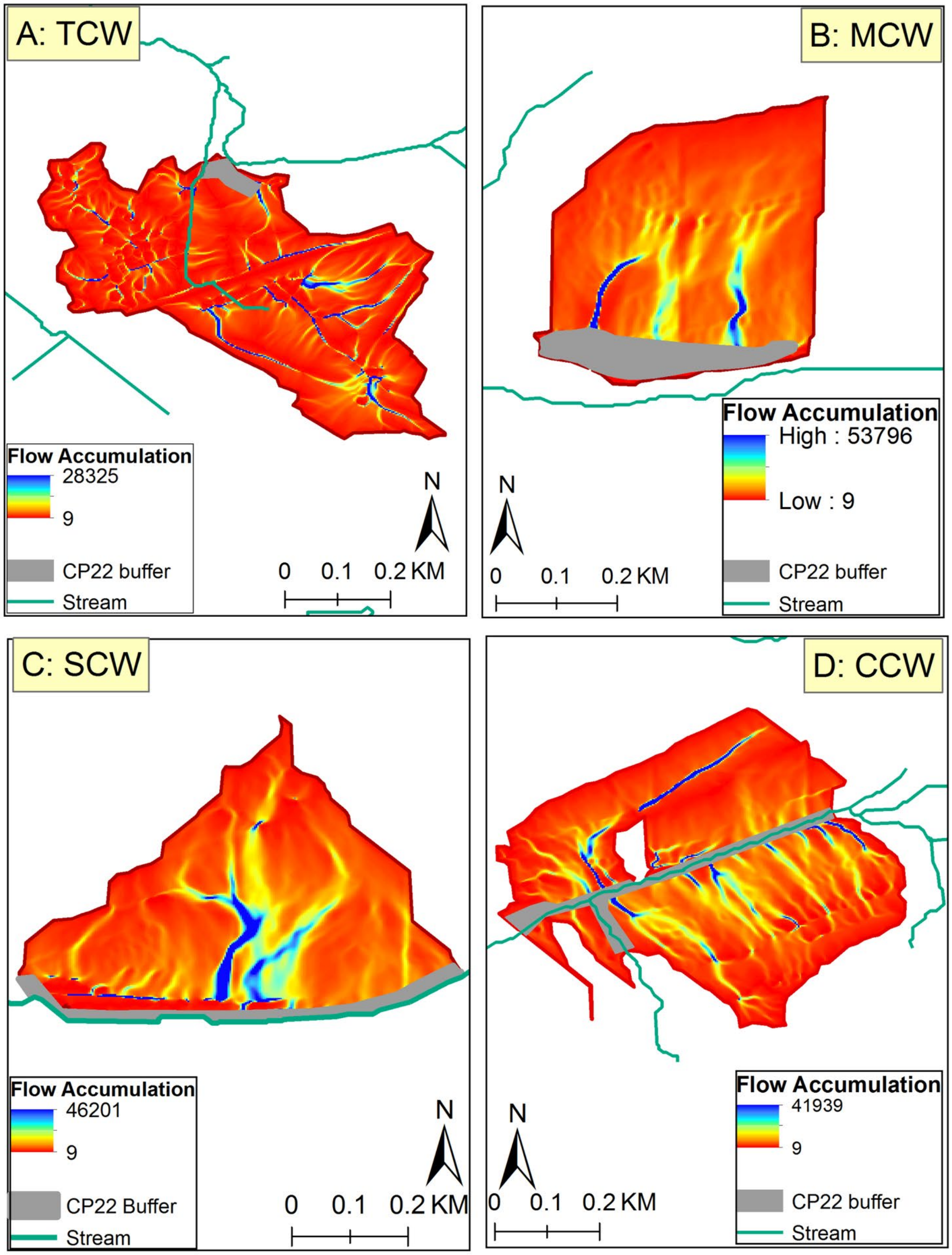


Figure 31. Maps of flow accumulation for riparian forest (CP22) buffers contributing areas in Tuckahoe Creek (TCW) [A], Mahantango Creek (MCW) [B], Spring Creek (SCW) [C] and Conewago Creek (CCW) [D].

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Publications resulting from study to date

Wallace, CW, G McCarty, S Lee, RP Brooks, TL Veith, PJA Kleinman, AM Sadeghi. 2018. Evaluating concentrated flowpaths in riparian forest buffer contributing areas using LiDAR imagery and topographic metrics. Remote Sensing 10(4):614 doi:10.3390/rs10040614

Presentations and requested briefings

Brooks, RP, MQ Nassry, C Fernandez, S Yetter, P Kleinman, G McCarty, T Veith, S Hyberg, R Iovanna, S Claggett, and L Duriancik. Performance of riparian buffers built as conservation practices in the Susquehanna River-Chesapeake Bay Ecosystem. Society of Wetland Scientists (SWS) Annual Meeting. Oral Presentation. Baltimore, MD. 28-31 May 2019.

Brooks, RP, C Fernandez, and MQ Nassry. Riparian Forest Buffers in the Susquehanna-Chesapeake: Performance of CREP Projects. Joint Wetlands Meeting (MAWWG & NEBAWWG), Cooperstown, NY. Oral presentation. November 14-16, 2018.

Fernandez, C, RP Brooks, and MQ Nassry. Assessment of CREP Riparian Forest Buffer Projects within the Susquehanna-Chesapeake Watershed. Society of Wetland Scientists (SWS) Annual Meeting. Oral presentation. San Juan, Puerto Rico. June 5-8, 2017.

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Appendices