Evaluating the Effectiveness of Economic Incentives to Enhance Riparian Buffer Adoption and Environmental Benefits for Water Quality and Carbon Sequestration in Maryland

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Executive Summary

Riparian buffers on agricultural land are a key component of efforts to improve water quality and achieve nutrient reduction goals for the total maximum daily load requirements in the Chesapeake Bay watershed. To incentivize buffer adoption, existing programs such as the Conservation Reserve Enhancement Program (CREP) offer agricultural landowners in Maryland financial incentives to voluntarily install forest or grass buffers. CREP had a large wave of enrollment in Maryland during the early years after being initiated in 1998, though the enrollment rate has slowed thereafter in recent years in spite of increased incentives. To bolster buffer adoption rates, Maryland's Conservation Buffer Initiative (CBI) provides an alternative incentive program compared to CREP. Two notably program changes in Maryland's CBI including shorter contract lengths and larger upfront payments in lieu of annual payments. This raises important questions regarding how agricultural landowners respond to different incentive program designs, in addition to the environmental outcomes and program costs.

This report provides analysis taking an experimental approach towards evaluating which types of program attributes are most effective to encourage agricultural landowners to install riparian buffers. In Part I, the report summarizes analysis of a survey of agricultural landowners throughout all counties in Maryland that elicited information on current riparian buffers and landowners' responses to enrolling in proposed alternative buffer incentive programs. The experiment embedded in the survey asked landowners about their willingness to enroll in alternative programs that varied in terms of contract lengths, upfront bonus payments, annual recurring payments, and buffer vegetation type (forest, grass). The economic model analyzed the likelihood of landowner enrollment in relation to program payments, contract length, farm management characteristics, and landowner demographics and attitudes. In Part II, an integrated assessment model was developed to provide the environmental outcomes resulting from riparian buffer adoption. To assess environmental benefits, spatially explicit biophysical models were developed that estimate parcel-specific nutrient reductions for riparian buffer adoption based on the Chesapeake Bay Watershed Model parameters and carbon sequestration for riparian forest buffers.

In Part III, several policy scenarios were analyzed to understand how changes in program design affects landowner participation rates, environmental benefits, and program costs. The overall goal was to improve the effectiveness of buffer incentive programs by providing insights into the incentive structures that increase landowner buffer installation and environmental outcomes. The scenario analysis used the current CREP structure as the baseline scenario and then compared alternative proposed designs on landowner participation and environmental outcomes, including those related to Maryland's CBI. Policy scenarios provided insights into tradeoffs on program design features, including: 1) upfront vs. annual payments, 2) short vs. long term contracts, 3) uniform vs. spatially varying bonus payments, and 4) with vs. without additional carbon payments.

Summary of Key Findings

- Landowners strongly preferred upfront payments in lieu of annual payments to incentivize riparian buffer installation. Scenarios that converted annual rental payments into a single large upfront payment successfully increased the landowner participation rates and program environment benefits for nutrient reductions and carbon sequestration.

- While shorter contract lengths slightly increased landowner participation rates, they significantly reduced the program environmental benefits and cost-effectiveness, primarily because of the shorter time window for environmental benefits from vegetation growth to accrue.

- Carbon offset payments are relatively low compared to the large incentives provided under CREP. When examining the potential for carbon offset payments at trading prices in the Regional Greenhouse Gas Initiative, the payment levels are substantially lower than those provided under existing buffer incentive programs, including CREP and Maryland's CBI. Allowing landowners to trade carbon sequestration offsets results in little additional adoption, at least for the case of riparian forest buffers.

- Scenarios offering targeted bonus payments to landowners based on parcel-specific environmental benefits improves program effectiveness and has the highest benefit-cost ratio amongst all scenarios analyzed in this study. Signing bonuses currently offered in Maryland under CREP are uniform (e.g., $1000 per acre for forest buffers), regardless of the environmental benefits achieved due to riparian buffer adoption. Bonus payments adjusted based on the expected environmental benefits at the parcel or watershed level is a potential low-cost approach to improve buffer program effectiveness given limited funds.

- The survey revealed that almost half of landowner respondents (46%) who had available land for riparian buffers choose not to enroll in any of the randomly assigned proposed programs, even those offering a signing bonus and/or annual recurring payments substantially higher than currently provided under CREP in Maryland. The economic model on factors affecting the likelihood of buffer program enrollment helps to differentiate the types of landowners who are more or less likely to enroll in buffer incentive programs.

Table of Contents

Introduction

Restoring riparian buffers on farmland is a centerpiece of efforts to improve water quality in the Chesapeake Bay watershed. Riparian buffers have accounted for 17%, 13%, and 20% of nitrogen reduction goals to meet the Bay total maximum daily load (TMDL) requirements, respectively, in Pennsylvania, Maryland, and Virginia (CBC, 2016). Nitrogen is the most problematic nutrient to reduce, with Maryland behind schedule on its nitrogen goal and not expected to meet the 2025 TMDL requirements (CBP STAC, 2023; EPA, 2024). Maryland had early success with the Conservation Reserve Enhancement Program (CREP) to incentivize farmers to adopt streamside buffers enrolling approximately 1,250 total miles in 1997-2004; however, after enrolling the "low hanging fruit", recent progress has slowed considerably to less than 250 total miles in 2005-2021 (DNR, 2022). A major study on forest cover revealed that tree canopy covers an estimated 58% of riparian zones throughout Maryland, still short of the 70% Bay watershed-wide goal (Minnemeyer et al., 2022).

Despite generous subsidy payments that have increased over time, CREP payments have been criticized as not being targeted in a cost-effective manner based on economic returns and site-specific environmental benefits. CREP provides subsidies to landowners who voluntarily enroll in 10- to 15-year contracts to convert land to grass or forest buffers in riparian areas currently in agricultural production. The subsidies include an upfront cost-share payment for buffer installation costs, plus an upfront signing bonus for enrollment. Additionally, the landowner receives annual rental payments according to the soil rental rate for foregone agricultural returns, as well as payments for buffer maintenance. CREP is a partnership between the federal government and state agencies. The State of Maryland has recently increased funding to provide a higher signing bonus at $1000 per acre for forest buffers (HB 991 Tree Solution Now Act) and fully cover installation costs (SB 344 Agriculture Cost-Share Program). While CREP is generous, the program design does not include any criteria to target according to site-specific variation in environmental benefits.

To increase buffer adoption, the Maryland's Conservation Buffer Initiative was recently created in 2021, administered by the Maryland Department of Agriculture (MDA, 2024). After talking directly with farmers, MDA created this program to provide greater flexibility not allowed under federal CREP rules, including shorter 5- to 10-year contract terms and a larger one-time upfront payment in lieu of annual payments. The need to expand enrollment raises important questions regarding how to increase BMP adoption and improve program effectiveness given a limited budget, as well as the relative importance of explicitly targeting using site-specific environmental benefits.

This report provides analysis of the incentive program features that are most effective in encouraging agricultural landowners in Maryland to plant riparian buffers. In Part I, the project used survey data from farmland owners throughout all counties in Maryland. This survey included parcel-level information on current riparian buffers and landowners' responsiveness to existing and proposed alternative incentive program designs. An experiment embedded in the survey elicited landowner enrollment decisions on alternative proposed programs that varied in terms of the contract length (5, 10, or 15 years), upfront one-time bonus payments, recurring annual payments, and buffer type (forest or grass). The economic model analyzed the landowner likelihood of enrollment in relation to program payments, contract terms, farm management characteristics, and landowner demographics and attitudes.

In Part II, the integrated assessment modeling approach is provided for the environmental and economic outcomes. Environmental outcomes include spatial models for site-specific estimates on: 1) nutrient load reductions for riparian buffer adoption based on the Chesapeake Bay Watershed Model parameters and other information (Belt et al., 2014), and 2) carbon sequestration for riparian forest buffers (Lamb et al., 2021; Ma Hurtt, and Lamb, 2022). The latter model on carbon sequestration provided data to explore whether voluntary carbon offset markets that pay farmland owners for sequestering carbon in forest buffers—a potential extra revenue source—would significantly increase landowner participation in existing incentive programs like CREP and Maryland's CBI.

In Part III, several policy scenarios are analyzed to understand how changes in program design affects landowner participation rates, environmental benefits, and program costs. The overall goal is to improve the effectiveness of buffer incentive programs by providing insights into the incentive structures that increase landowner buffer installation and environmental outcomes. The scenario analysis used the current CREP structure as the baseline scenario and then compared alternative proposed designs on landowner participation and environmental outcomes, including those related to Maryland's CBI. Policy scenarios provided insights into tradeoffs on program design features, including: 1) upfront vs. annual payments, 2) short vs. long term contracts, 3) uniform vs. spatially varying bonus payments, and 4) with vs. without additional carbon payments.

Part I: Landowner Survey on Buffer Incentive Programs

Farmland Owner Survey on Riparian Buffers in Maryland

In the summer of 2021, our research team at the University of Maryland conducted a farmland owner survey across all counties in Maryland. The survey questionnaire was developed over a two-year process with input and collaboration from state and federal agencies, extension agents, and other stakeholder groups involved with riparian buffer programs. The purpose of the survey was to understand the types of incentive structures and landowner and farm/parcel characteristics that influence landowners' likelihood of adopting riparian buffers.

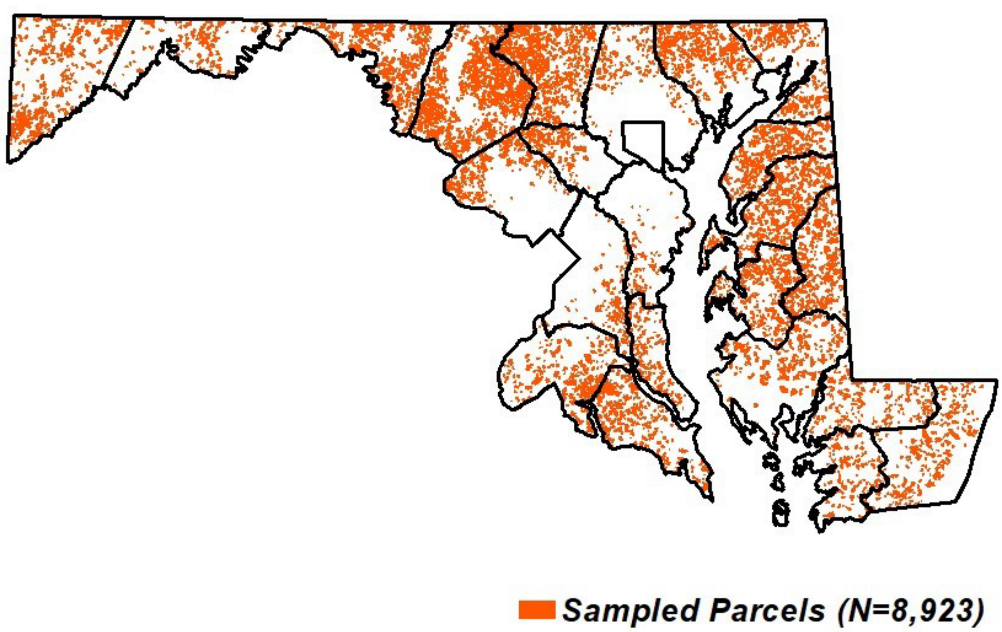

Figure 1. Agricultural Landowner Parcels in Riparian Buffer Survey

The survey sample was initially derived from the complete spatially explicit parcel-level tax assessor database for agricultural properties from the Maryland Tax and Assessment Office. The survey sample was screened to include only agricultural landowner parcels that met the following criteria: 1) parcels with at least 10 acres of crops, hay, or pasture according to the USDA Cropland Data Layer; and 2) parcels that intersect or are adjacent to waterbodies (stream, rivers, wetlands) that are eligible for riparian buffers using the USGS National Hydrography Data. Any landowner with multiple parcels was sent the survey for a single randomly selected parcel. The final survey sample resulted in 8,923 landowner parcels, in which Figure 1 maps these parcels showing the widespread coverage of sampled parcels across all 23 Maryland counties.

The survey was administered via push-to-web method for these parcels between May and July 2021. Participation was solicited through mailed invitation letters to each landowner that provided a survey link (URL) for an online survey via Qualtrics, with an option to request a paper copy of the survey. Each landowner had a unique ID and password that allows the survey response to be spatially linked to the parcel address. A total of 1,530 landowner responses was received (1,420 online and 110 by mail), resulting in a response rate of 17%.

The first part of the survey asked respondents about whether the parcel has any existing riparian buffers. For a landowner with an existing buffer, the survey elicited further information on the buffer type (forest, grass), time period installed, buffer acreage, and whether cost-share funding was received from CREP or similar buffer subsidy program. Landowners were allowed to provide detailed information separately on multiple buffers, if applicable, for the three largest riparian buffers. The first part of the survey also collected information regarding: 1) farm operation (farm income, crop types, % rented land); 2) landowner demographics (age, education); 3) attitudes towards risky investments and government farm programs; and 4) participation in farm support programs. This information was used to assess landowner and farm/parcel characteristics that affect the likelihood of adopting riparian buffers. Additionally, the second part of the survey created an experiment on alternative buffer incentive programs and will be discussed below in detail.

Trends on Buffer Adoption History

Table 1 provides the summary of the number of landowners with forest and grass riparian buffer adoption over time. CREP was initially established in Maryland in 1998, and then program rules changed in 2009 to include more eligible lands and higher cost-share payment rates. For this reason, the initial time period for buffer installation is reported in three periods: before CREP (pre-1998), initial CREP period (1998-2009), and recent CREP period until survey conducted (2009-2021).

Several interesting findings are revealed in the forest buffer adoption data in Table 1. First, the vast majority of forest buffers already existed in 1998 before the introduction of CREP and are self-funded at the landowner's expense (i.e., no subsidy received). This suggests that most forest buffer acreage (or stream miles) for landowners in Maryland are not funded with incentive payments. Instead the forest buffers have existed prior to CREP, presumably on riparian land primarily less suitable for agriculture production in crops, pasture or hay. Second, after CREP became available, the forest buffers enrolled in a cost-share program has become more substantial, though almost half of forest buffers installed have been self-funded by the landowner. Lastly, the grass buffer adoption data in Table 1 follows similar trends as forest buffers, but there are far fewer grass buffers that existed prior to 1998.

Table 1. Riparian Buffer Installation for Number of Landowners with and without Cost-Share Program Enrollment

	Forest buffers		
	Pre-1998	1998-2009	2009-2021
Enrolled in cost-share program	25	61	37
Self-funded	429	49	38
% buffers enrolled	5.5%	55.5%	49.3%
	Grass buffers		
	Pre-1998	1998-2009	2009-2021
Enrolled in cost-share program	38	54	44
Self-funded	217	70	35
% buffers enrolled	14.9%	43.5%	55.7%
N=1,468 landowners			

Experiment on Alternative Buffer Incentive Programs

The survey included an experiment to understand how individual landowners respond to enrolling under alternative hypothetical program designs. Because the goal is to understand how to incentivize new riparian buffers, the experiment was purposefully shown only to those landowners who had not yet planted any buffers or had available land to install additional riparian buffers. Table 2 describes the program attributes that were varied in the experiment related to the buffer type, upfront bonus payment, annual recurring payment, and contract length. This experiment used program attributes relevant to CREP and Maryland's CBI, and it encompassed a wide range of alternative programs.

The experiment elicited how landowners respond to varying program design features by presenting them with a series of proposed hypothetical buffer incentive programs and asking whether or not they would enroll in the proposed program given the offered terms. Figure 2 displays an example of the enrollment choice question for what a survey respondent saw regarding a hypothetical buffer program. This figure shows the example of a program for forest buffers that offers an upfront bonus at $500 per acre, recurring annual payments at $250 per acre, and the contract length for 10 years. The landowner is then asked: "Would you enroll in this program? (Yes/No)".

Table 2. Program Attributes for Alternative Proposed Buffer Programs in Survey Experiment

Program Attribute	Description
Vegetation type	Vegetation type of the riparian buffers: forest or grass
Upfront payment	One-time upfront bonus payment for program enrollment: $200, $500, $1,000, or $1,500 per acre
Annual payment	Recurring annual payments for a specified contract period: $100, $250, $500, or $750 per acre
Contract length	Number of years to maintain the established buffers: 5, 10, or 15 years

Table 2 shows the program attributes and levels that yield 48 different possible combinations of programs and were used to create enrollment choice questions similar to Figure 2. This table shows the buffer vegetation type included either forest or grass buffers, as commonly available in CREP. The one-time upfront bonus payment had four possible levels, varying from $200 to $1500 per acre. Additionally, the recurring annual payment had four possible levels, varying from $100 to $750 per acre, which is received in each year of the contract. The alternative programs included the contract length offered for 5, 10, or 15 years. These contract lengths allow us to examine the effect of longer contracts under CREP and those shorter contract lengths offered under Maryland's CBI.

Example: A Possible Program

Each question will ask whether you would choose to enroll in a possible program. Questions will look similar to the "Example" table below, but with different program options to consider. Please remember that:

- Installation costs and maintenance costs will be fully covered by the program, regardless of the buffer type offered in the program
- You will receive the one-time bonus payment **at the time you enroll in the program**
- The program requires a minimum buffer width of 35 feet

Program element	**Program X**
Buffer type	Forest buffer
Bonus payment ($/acre)	$500
Annual payments ($/acre)	$250
Contract length (years)	10

The payment schedule for **Program X** will look like the following "Example" table:

	Program X
Year 0 – Bonus payment ($/acre)	$500
Year 1 – Annual payment ($/acre)	$250
Year 2 – Annual payment ($/acre)	$250
Year 3 – Annual payment ($/acre)	$250
Year 4 – Annual payment ($/acre)	$250
Year 5 – Annual payment ($/acre)	$250
Year 6 – Annual payment ($/acre)	$250
Year 7 – Annual payment ($/acre)	$250
Year 8 – Annual payment ($/acre)	$250
Year 9 – Annual payment ($/acre)	$250
Year 10 – Annual payment ($/acre)	$250
	Contract ends

Would you enroll in **Program X**? (Choose one)

○ Yes – I would enroll

○ No – I would not enroll

Figure 2. Example of Enrollment Choice Question for a Proposed Buffer Program in Landowner Survey

In the experiment, each survey respondent was presented with four randomly selected programs (4 out of 48 possible programs). Each program assigned had a different set of program attributes shown to the respondent in the format used in Figure 2. Then the respondent was asked to answer the whether they would enroll (yes/no) for each of the four separate programs. For simplicity, all buffer programs stated that the buffer width must be at least 35 feet, and the installation and maintenance costs are covered by the program. The experiment was shown to those 538 landowners without buffers or available land for buffers, and yielded responses to 2,111 enrollment choice decisions.

Factors Affecting the Likelihood of Buffer Program Enrollment

The experiment embedded in the survey provided the data for statistical models to estimate which factors are most influential in determining enrollment in proposed buffer incentive programs. Specifically, we analyzed the program design attributes and landowner/parcel characteristics affecting the likelihood of program enrollment for adopting a riparian buffer. Statistical analysis was conducted using a logit regression model. This is a standard statistical model used when there is binary choice, i.e., when the landowner chooses whether to enroll in a given program (yes/no).

Table 3. Summary Information on Landowner and Farm-Parcel Characteristics from Survey Respondents Answering Experiment on Alternative Program Designs

Variable	Description	Mean	Min	Max
Crop return*	Foregone annual crop income ($/acre/year)	294	17	774
Farm income	Share of household income from farming	0.16	0	1
Indicator Variables (=1 if Yes, =0 if No)				
Senior	Age over 65	0.56	0	1
College	Has a college degree or higher	0.61	0	1
Rent	Rents out some or all farmland within the parcel	0.50	0	1
Risk averse	Is risk averse	0.27	0	1
Conservation subsidy	Received payments for buffers already existing on parcel	0.06	0	1
Self-funder	Landowner self-funded buffers already existing on parcel	0.27	0	1
Farm support	Participates in any farm support programs: crop/revenue insurance, livestock insurance, Farm Service Agency loans, dairy margin coverage or margin protection program, price support programs (commodity loans, loan deficiency payments, etc.)	0.23	0	1
Opposition to property monitoring	Agrees with statement: "The government should not be allowed to come onto my property and monitor my farmland operations"	0.61	0	1
Opposition to tax-funded farm programs	Agrees with statement: "Tax revenues should not be used for farm support programs"	0.19	0	1

Note: The table includes summary data from 538 landowner parcels who completed the survey experiment with alternative program design questions.

* Foregone annual crop return is approximated using national commodity crop productivity index and cash rental rate for non-irrigated cropland following Kim et al. (2024).

There are two main types of explanatory variables used to understand factors affecting the likelihood of landowner enrollment. The first type are the program attributes in Table 2 related to buffer type, upfront payment, annual payments, and contract length. The second type are farm/parcel characteristics on farm management and land quality, as well as landowner demographics and attitudes about farm programs and risk. Table 3 provides a summary of these landowner and farm/parcel characteristics that the landowner provided in the survey questionnaire. The exception is the site-specific crop return variable, which we computed using the National Commodity Crop Productivity Index for each landowner parcel combined with cash rental rates for non-irrigated cropland (Kim et al., 2024).

Table 4. Determinants of Enrollment in Riparian Buffer Program

Factors	Likelihood of Program Enrollment
Program attributes	
Forest buffer (baseline: grass buffer)*	0
Upfront payment	+
Annual payment (baseline: 15-year contract)	+ +
Annual payment × 5-year contract	0
Annual payment × 10-year contract	0
Landowner and parcel characteristics	
Crop return	− −
Farm income share	−
Senior	− −
College	0
Rent	+
Risk averse	− −
Conservation subsidy	+ +
Self-funder	+ +
Farm support	−
Opposition to property monitoring	− −
Opposition to tax-funded farm programs	−
Number of observations: 538 landowner parcels (2,111 program choice observations)	

* In addition to variables shown above, the estimation includes binary indicators for parcels with missing characteristics and interaction terms for delays on upfront payments.
++: Positive relationship at 1% confidence level; +: Positive relationship at 5% confidence level;
- -: Negative relationship at 1% confidence level; -: Negative relationship at 5% confidence level;
0: No significant relationship

Table 4 show the main results from the statistical model on the factors affecting the likelihood of program enrollment. That is, this table presents the program attributes and landowner/parcel characteristics that are positively or negatively associated with enrollment in buffer incentive programs. The primary interest is to understand how landowners responded to the four program attributes varied in the experiment. First, survey respondents did not show a statistically significant difference in their preferences for enrolling in programs featuring forest buffers compared to the grass buffers. This similar preference for forest and grass buffer types may be partly due to the installation and maintenance costs being covered by the program, as assumed in the experiment. Second, larger upfront bonus payments were positively associated with higher program enrollment, as expected. Additionally, the annual payment levels have a strong positive relationship with the landowner decision to enroll. Third, we compared the annual payments for the three different contract lengths (5, 10, and 15 years) using a 15-year contract as a baseline. The results indicate that contract length did not affect the likelihood of enrollment. In other words, landowners did not have a significant preference for shorter contract lengths (5 or 10 years) compared to the 15-year baseline contract. Lastly, after further analysis on the upfront and annual payments, we found that both payment types increase enrollment, though landowners have a strong preference for upfront payments. These last two results are especially policy relevant, as Maryland's CBI has recently implemented changes to the traditional CREP structure. Our results from Table 4 suggest that higher upfront bonus payments in lieu of annual payment may be highly effective at increasing participation rates. However, the program change to shorter contract lengths did not alter participation rates significantly, according to our experimental evidence.

Table 4 also includes the main results on landowner and farm/parcel characteristics that positively or negatively affect the likelihood of program enrollment. Interestingly, our survey data revealed that 46% of landowners in the experiment choose not to enroll in any of the four randomly assigned proposed programs. This means that they rejected all programs, even with those offering upfront bonus and/or annual payment levels in Table 2 that are substantially higher than currently provided under CREP in Maryland.

Table 4 helps to distinguish the types of landowners who are more or less willing to enroll in buffer incentive programs. For example, landowners with higher crop return are less likely to enroll in buffer incentive programs. This result indicates a general hesitance of landowners who earn higher crop returns to participate in buffer incentive programs, potentially resulting in lower profits than could have been realized under maintained crop production. Landowners who are older (>65 years) are less likely to enter long-term buffer contracts, compared with younger landowners. Consistent with intuition, landowners who self-report that they are more risk averse, opposed to government's property monitoring, and opposed to tax-funded farm programs are all less likely to enroll in the buffer program. Meanwhile, landowners who already self-fund existing buffers on their parcels and who already have experience with conservation subsidy programs are more likely to enroll in the program.

Part II: Integrated Assessment Model of Environmental and Economic Outcomes

Overview of Integrated Assessment Model

Results from the econometric modeling reveal important insights about how agricultural landowners in Maryland respond to varying attributes of hypothetical buffer incentive programs when choosing whether or not to enroll. We construct an integrated assessment model (IAM) that combines the likelihood of landowner enrollment from the econometric model with assessments of the site-specific environmental benefits for nutrient reductions and carbon sequestration resulting from buffer adoption. The IAM is used to examine several policy scenarios on alternative programs and the outcomes on landowner participation rates, environmental outcomes, and program costs. The remainder of this section provides the detailed methodology for the spatially explicit biophysical models of water quality and carbon sequestration benefits for riparian buffers in Maryland.

Water Quality Benefits Model

The water quality benefits model characterizes the spatial variation in estimated N and P load reductions for installing riparian forest and grass buffers on agricultural land parcels in Maryland. The water quality model is based on the spatially varying parameters from the Chesapeake Bay Watershed Model (CBWM) used by the EPA and jurisdictions in the Bay watershed, as well as information from expert panels of scientists and agency staff (Belt et al., 2014; CBP, 2020; Hood et al., 2021). Specifically, the spatial variation in nutrient reductions relies on three CBWM parameters, including (1) N and P loads for initial cropland and buffer type, (2) buffer practice nutrient removal rates, and (3) delivery factors from each land-river segment to the Bay.

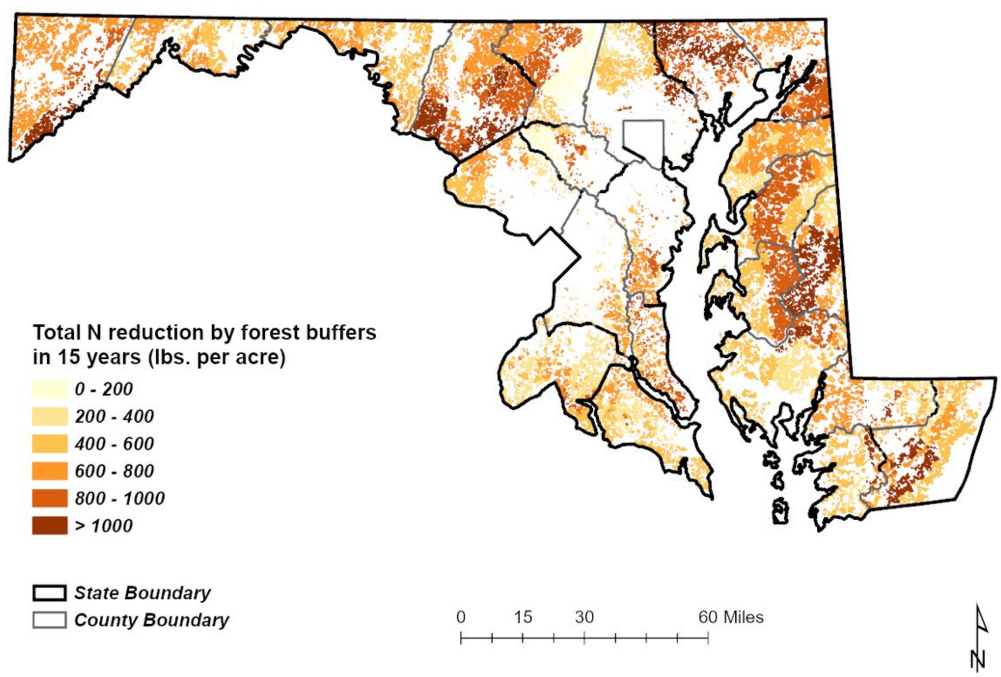

Figure 3. Parcel-Level Total Nitrogen Load Reduction (N Pounds per Acre) for Forest Buffers in 15-Year Contract

Consider, for example, a landowner parcel initially with cropland in the riparian area that is converted to forest buffer installation (analogous methods are used for grass buffer installation). The model uses the high-resolution land use data from the Chesapeake Conservancy (2024) to determine land use in cropland within each parcel's 35-foot riparian zone for surface waterbodies (e.g., streams, rivers). First, the difference in nutrient loading rates between cropland and forest buffer were calculated in N and P pounds per acre, respectively. Second, the BMP efficiency rates are incorporated for forest (or grass) buffers, which measure how effectively buffers filters and reduces loads from remaining cropland. Nutrient removal rates vary by buffer type and age, and by hydrogeomorphic region (Belt et al., 2014; Simpson and Weammert, 2009). For instance, forest buffers have a higher nitrogen removal rate than grass buffers when fully mature, but the rate increases more slowly compared to grass buffers (Belt et al., 2014; Hairston-Strang, 2005). Third, delivery factors account for the proportion of loads from the land-river segment that reach the Bay. Water quality benefits include both direct effects of converting cropland to buffers in the riparian area and the indirect effects of buffers reducing nutrient loads from remaining nearby cropland.

Figures 3 and 4 display the water quality model estimates for the N and P load reductions, respectively, in pounds per acre for cropland converted to forest buffer for a 15-year contract length. Significant spatial variation is observed throughout the state, according to differences in CBWM parameters on the loading rates, buffer efficiency rates, and delivery factors discussed earlier. For example, in the case of N load reductions in Figure 3, buffer efficiency rates on the Eastern Shore are lower in tidally influenced coastal areas but are higher further inland based on the hydrogeomorphic region (Belt et al., 2014). This means that buffers closest to the shore perform relatively worse at filtering nutrients and reduce lower amounts of N loads. The water quality model was used to calculate N and P load reductions for different buffer types (forest or grass) and contract lengths (5, 10, or 15 years) corresponding to the alternative proposed buffer programs in the survey experiment.

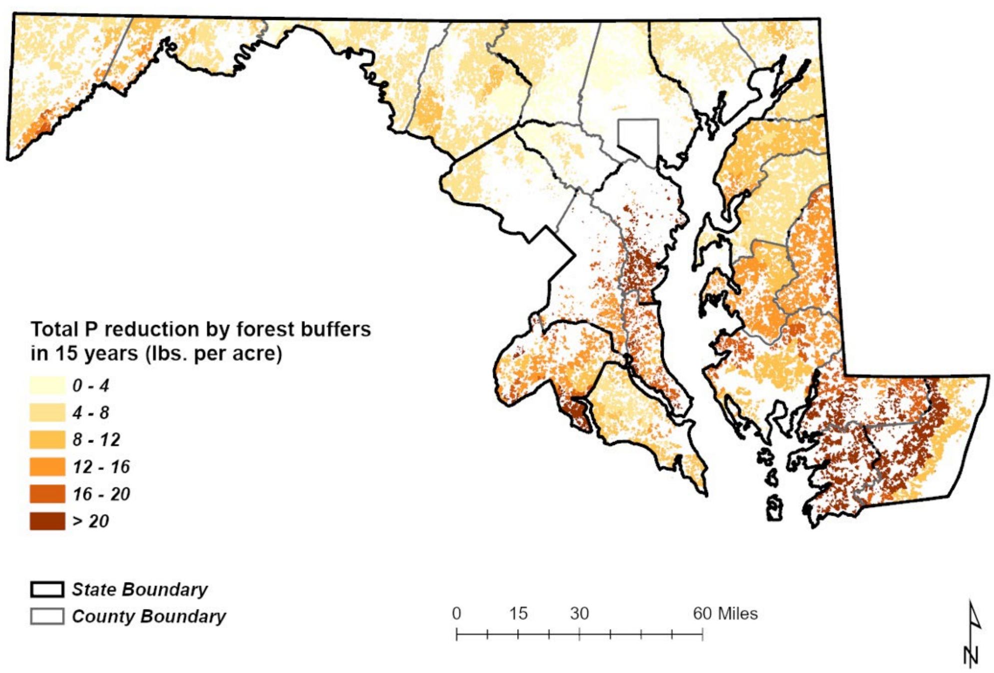

Figure 4. Parcel-Level Total Phosphorus Load Reduction (P Pounds per Acre) for Forest Buffers in 15-Year Contract

The water quality model results displayed in Figures 3 and 4 show estimates of physical quantities of N and P load reductions from buffer installation. The final step of the model translates these physical quantities into estimates of the monetary value of these water quality benefits. These benefits are defined as the costs that society does not incur (avoided social cost) as a result of reductions in pollutant loads reaching the Chesapeake Bay. The model uses the social costs from Choi et al. (2020), which are estimated to be \$17.11/pound N reduced and \$207.66/pound P reduced for the Chesapeake Bay region. In other words, the total water quality benefit is calculated using these estimates of per-pound benefit of N and P load reductions from Choi et al. (2020) multiplied by the corresponding physical N and P load reductions in each year; and then discounted over the life of the contract using a 2.5% discount rate. This modeling approach yields a dollar value for the water quality benefits from buffer adoption specific to each landowner parcel, an important outcome used in the policy scenarios below.

Carbon Sequestration Benefits Model

Tree cover planted on lands previously in crop production provides environmental benefits through carbon sequestration. Similar to the water quality benefits model, the C sequestration benefits model is constructed as part of the IAM to estimate aboveground forest carbon storage from the adoption of forest buffers on riparian land that is initially devoted to cropland. Our model relies on the high-resolution forest carbon modeling data pioneered in Maryland and later extended to the entire northeastern United States (Hurtt et al., 2019; Lamb et al., 2021; Ma et al., 2021). In these studies, the initial tree cover and biomass data were calibrated from remote sensing imagery and high-resolution LIDAR for tree height data. These data inputs were used in the Ecosystem Demography Model (version 3.0), which is an ecosystem model that uses variables such as weather conditions (temperature, precipitation, etc.) and soil characteristics (depth, water retention, etc.) to estimate aboveground forest carbon storage over time at a 30-meter resolution (Ma, Hurtt, and Lamb, 2021; Ma et al., 2022).

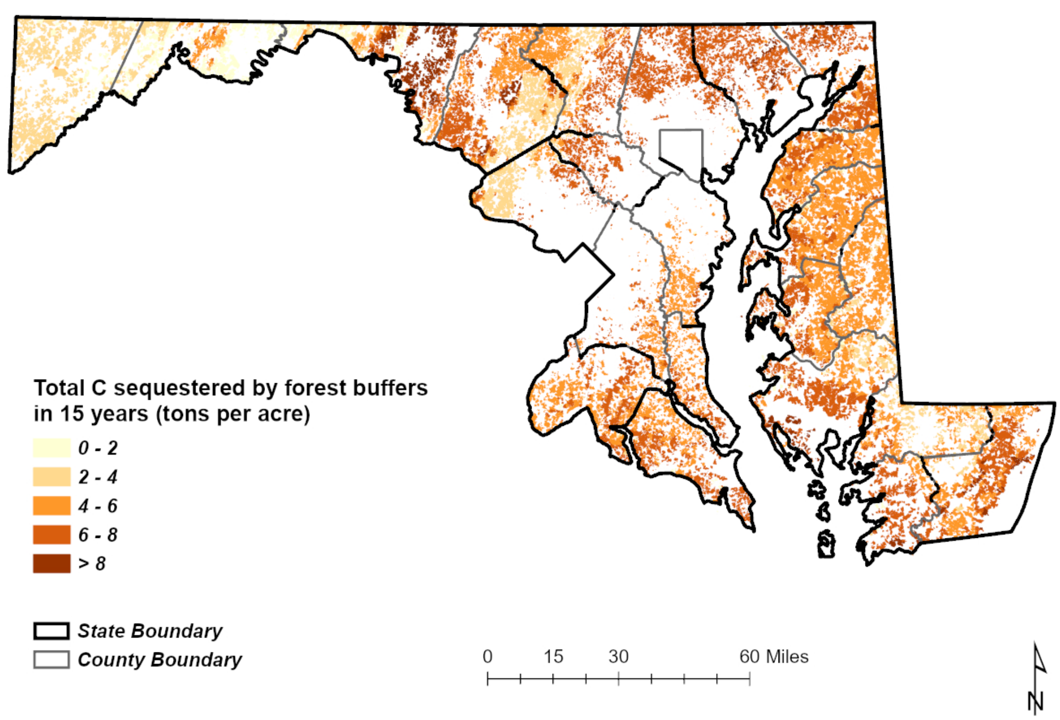

Figure 5. Parcel-Level Total Carbon Sequestration by Forest Buffers in 15 Years (tons per acre)

For our purposes, C sequestration is estimated for each landowner parcel as the aboveground forest carbon storage (in C tons per acre) for a forest buffer over the contract length (e.g., 15 years), assuming the trees are planted on land initially in agricultural production. Figure 5 shows the parcel-specific C sequestered by forest buffers for a 15-year contract, revealing regional heterogeneity in aboveground C storage across the state of Maryland. Lower C storage estimates are found in western Maryland due to factors such as cooler temperatures, shorter growing seasons, and shallower soil depths in rocky hillside areas. Meanwhile, higher C storage estimates are found in eastern and southern Maryland where relatively warmer temperatures, longer growing seasons, and higher soil quality in the coastal plains are more prevalent. Two model limitations are worth noting. First, the forest carbon modeling data used here (Hurtt et al., 2019; Lamb et al., 2021; Ma, Hurtt, and Lamb, 2022; Ma et al., 2022) only estimates aboveground C storage, not the belowground C storage. Second, these studies do not have available data on C storage for grass buffers.

The final step of the model translates the physical quantities for forest carbon sequestration, as displayed in Figure 5, into monetary benefit estimates. C benefits are estimated by multiplying the physical quantities by the social cost of carbon, which is the avoided cost to society for each ton of C sequestered. The social cost of carbon is estimated at $418/ton C for permanent storage (Carleton and Greenstone, 2022; EPA, 2023), which must be discounted to consider only the contract length (e.g., 15 years) instead of permanent storage. The C benefit estimates are the discounted benefits accrued over the contract period using a 2.5% discount rate similarly applied in the water quality model. This approach yields a dollar value for the C sequestration benefits to society from forest buffer adoption specific to each landowner parcel, an important environmental outcome to be used alongside the water quality benefit estimates in the policy scenarios outlined below.

Part III: Policy Scenarios

Overview of Policy Scenarios

Several policy scenarios are examined to understand how alternative buffer incentive programs affect landowner participation rates, environmental benefits, and program costs. Each policy scenario is simulated using the IAM that combine landowner likelihood of enrollment from the econometric modeling with the biophysical models of water quality and carbon sequestration. In the first step, the econometric model predicts the likelihood enrollment for each landowner (n=538 landowners participating in the survey experiment) to the payments offered under a given policy scenario. This yields the expected landowner participation rate for those landowners who participated in the survey experiment (n=538 landowners) and the expected total program costs under this scenario. In the second step, the total environmental benefits are calculated for those landowner parcels that choose to enroll in the first step. This includes the water quality benefits for N and P load reductions, as well as carbon sequestration benefits for scenarios with forest buffers.

Table 5 summarizes the five policy scenarios that are analyzed for forest buffers, and then repeated to analyze the case of grass buffers. The first scenario is the "baseline CREP" scenario designed to characterize the current CREP payments and contract lengths available to agricultural landowners in Maryland ("Baseline CREP" in Table 5). For forest buffers, the baseline CREP scenario offers to pay landowners for all buffer installation costs (100% cost-share), plus an upfront signing bonus of $1,000 per acre. Additionally, the landowner receives annual payments equal to three times the parcel-specific soil rental rate (SRR) for a 15-year contract period for forest buffers. SRRs are annual rental rates (in $ per acre) determined the USDA FSA, according to the parcel-specific soil productivity and county-specific rental rates for non-irrigated cropland used to compensate farmers for foregoing crop production on riparian land converted to buffers under CREP. Figure 6 shows the spatial distribution of SRR that we calculated based on the area-weighted average SRR for the three dominant soil types in the 35-foot riparian buffer zone for each agricultural parcel in Maryland. This figure reveals higher SRR values for the upper Eastern Shore with highly productive agricultural lands, while lower SRR values prevail in western Maryland with more hilly terrain and cooler temperatures. The baseline CREP scenario for grass buffers assumes that landowners receive compensation for all buffer installation costs (100% cost share), plus an upfront signing bonus of $200 per acre. The landowner also receives annual payments equal to 2.5 times the SRR for a 10-year contract period, as done under CREP. The CREP scenarios used the average installation costs in Maryland estimated at $2,100 per acre for forest buffers and $330 per acre for grass buffers (Price, Hollady, and Wainger 2019).

Table 5. Description of Policy Scenarios

Policy Scenario	Summary Description

Baseline CREP	• Full (100%) cost-share for buffer installation
	• Signing bonus upfront = $1,000/acre (forest); $200/acre (grass)
	• Annual rental payment based on parcel soil rental rate (SRR)
	  o Forest buffer: 3*SRR for 15-year contract
	  o Grass buffer: 2.5*SRR for 10-year contract

All payments upfront	• Same as Baseline CREP, except convert present value of annual rental payment into a single upfront payment

Shorter contract lengths	• Same as Baseline CREP, except shorter contract length
	  o Forest buffer: 10-year contract
	  o Grass buffer: 5-year contract

Targeted bonus payments	• Same as Baseline CREP, except change signing bonus from uniform $1,000/acre to a targeted payment that varies spatially by the site-specific N reductions achievable on each parcel
Baseline CREP, plus carbon offset payments	• Same as Baseline CREP, plus additional payments for carbon sequestration storage over contract length (forest buffers only)

The next two policy scenarios in Table 5 are inspired by the program design in Maryland's CBI, administered by MDA. Relative to CREP, this buffer incentive program made two major changes: 1) higher upfront payments in lieu of annual payments, and 2) shorter contract lengths. We created two separate policy scenarios to examine each program change individually, relative to the baseline CREP scenario. The "upfront payments only" scenario is exactly the same as the baseline CREP scenario, except that the annual payments are converted into a single upfront payment. That is, the sum of annual payments for 15 years at 3 times the parcel's SRR in the forest buffer contract is converted into the present value as a single upfront payment. Similarly, the grass buffer contract converts the sum of annual payments for 10 years at 2.5 times the parcel-specific

SRR into an upfront payment. The "shorter contract length" scenario is the same as the baseline CREP scenario, except that grass and forest buffer contract lengths are 5 and 10 years, respectively (instead of 10 and 15 years under the baseline CREP scenario).

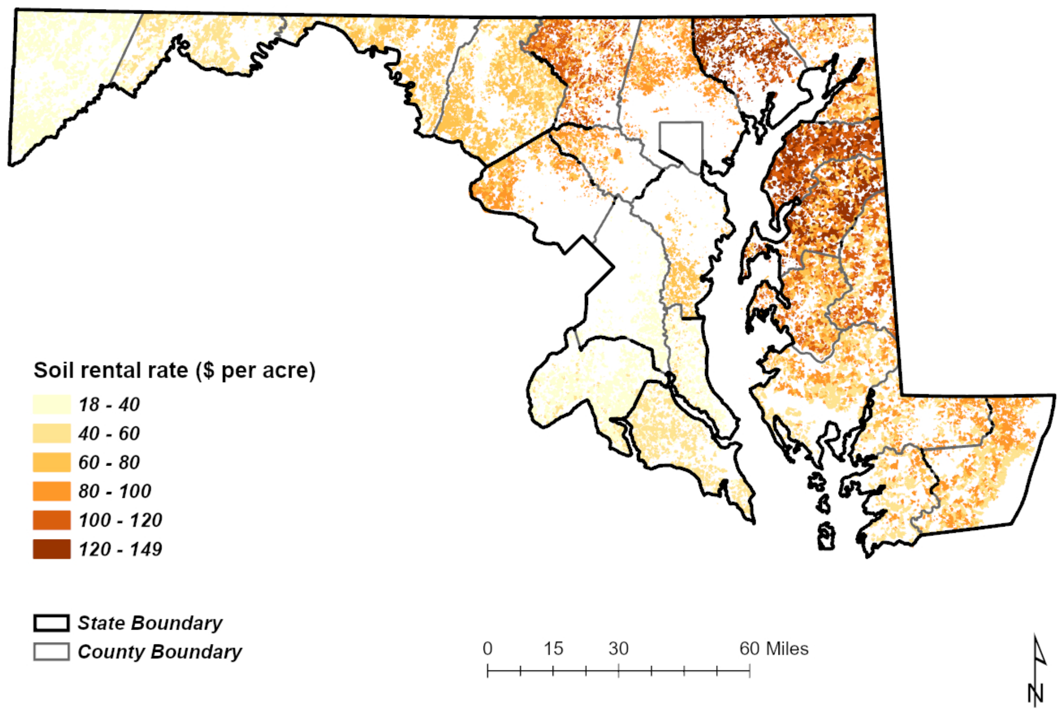

Figure 6. Parcel-Level Soil Rental Rate ($ per acre)

Additionally, we examine the importance of spatially targeted upfront signing bonuses. Under the baseline CREP scenario, a uniform signing bonus of $1000 per acre is offered for forest buffers statewide, regardless of the environmental benefits achievable through buffer adoption on any parcel. Uniform policies are well known to be inefficient when substantial variation exists across farmland parcels. The "targeted bonus payments" scenario in Table 5 is the same as the baseline CREP scenario, except that the signing bonuses are adjusted to vary spatially based on the parcel-specific N load reductions (Figure 3), relative to the average N load reduction for all parcels. Parcels with higher N load reductions from forest buffers receive a signing bonus greater than $1,000 per acre, while parcels with lower N reductions receive a signing bonus below $1,000 per acre. As a specific example, a landowner parcel with N load reduction 50% above average would receive a bonus at $1500 per acre, whereas a parcel with N load reduction 20% below average would receive a bonus of $800 per acre.

Lastly, we examine the scenario where carbon offset payments for forest buffers are made above and beyond those payments under the baseline CREP scenario (labeled as "baseline CREP, plus carbon offset payments" scenario in Table 5). Landowners are offered payments for the estimated C sequestered in forest buffers over the contract period, based on the parcel-specific C sequestration model estimates (Figure 5). Payments for C sequestration in forest buffers are estimated by multiplying C storage estimates on each parcel with recent trading prices in the

Regional Greenhouse Gas Initiative (RGGI), a well-established carbon market for the electricity sector in the northeastern United States. The RGGI trading prices are approximately $35 per ton C. This scenario is examined for forest buffers only. As explained above, the carbon sequestration model is only available to estimate aboveground forest carbon storage, not for carbon sequestration in grass buffers. This scenario examines whether a policy change that allows the stacking of carbon payments with those already received through CREP for forest buffers would be sufficient to induce increased program participation.

Main Findings from Policy Scenarios

The IAM was used to compare environmental and economic outcomes for each of the five policy scenarios outlined in Table 5. Each scenario was simulated for forest buffers in Table 6 and summarizes the main results on landowner participation rates, total environmental benefits, and total program costs. Starting with the "baseline CREP" scenario, the results indicate a landowner participation rate of 16.4% who are willing to enroll and install forest buffers under the current CREP payment levels for a 15-year contract. For those landowners in the survey experiment, the total environmental benefits are $2.36 million while total program costs are $1.23 million (i.e., benefit-cost ratio at 1.91 substantially greater than one). The vast majority of the environmental benefits are related to N load reductions (84%), while the C sequestration benefits are quite small (2%) for forest buffers after 15 years of tree cover growth.

Table 6. Policy Scenarios for Forest Buffer Program Performance

	Baseline CREP	All payments upfront	Shorter contract lengths	Targeted bonus payments	CREP + carbon payment
Participation rate					
% of landowners	16.4%	27.9%	17.3%	17.3%	17.5%
Total benefits and costs ($ in millions)					
Total benefits	2.36	4.04	1.71	2.60	2.53
Total costs	1.23	2.15	1.12	1.32	1.36
Net benefits	1.13	1.89	0.58	1.28	1.17
Benefit/cost ratio	1.91	1.88	1.52	1.96	1.86
Benefit type (% of total benefits)					
Nitrogen benefits	84%	85%	85%	85%	84%
Phosphorus benefits	14%	13%	14%	13%	14%
Carbon benefits	2%	2%	1%	2%	2%

When considering the "all payments upfront" scenario, the results in Table 6 indicate that the landowner participation rate increases dramatically to 27.9%. This reveals landowners' strong preferences for upfront payments, showing that higher upfront payments can induce increased participation in buffer incentive programs, as done in Maryland's CBI. Nonetheless, the benefit-cost ratio is 1.88 for this scenario, which is quite similar to the 1.91 ratio in the baseline CREP scenario. This suggests that the upfront payments substantially increases landowner enrollment, but it does not necessarily target landowners with higher benefits more effectively.

For the "shorter contract length" scenario, participation rates are slightly higher (17.3%) than the baseline CREP scenario. However, the benefit-cost ratio decreases to 1.52, which is the lowest level amongst all five scenarios. The reason is that the shorter contract still has similar upfront costs (i.e., cost-share for installing forest buffers, signing bonus) to induce landowners to participate voluntarily. Yet the shorter contract length allows less time to accrue the environmental benefits for N, P, and C under the 10-year forest buffer contract. In sum, offering shorter contract lengths as a program change is likely to decrease the program effectiveness, according to the landowner response in our survey experiment.

The "targeted bonus payments" scenario shows a slight increase in participation rates and program net benefits compared to the baseline CREP scenario. Notably, this scenario achieves the highest benefit-cost ratio amongst all five scenarios in Table 6. Spatially varying bonuses provides a straightforward approach to better allocate the limited program funds towards the landowner parcels with the greatest environmental benefits. This targeting scenario is a modest approach to create spatially varying payments. For example, a parcel with 50% higher N load reduction would receive a bonus of $1,500 per acre (an extra $500 per acre). This is a small bonus incentive compared to other CREP payments for installation costs and sum of annual payments, as outlined below in Table 7. Targeting bonus payments has clear potential to improve program effectiveness, though the bonus level would need to be higher to make a more substantial difference.

Finally, the scenario for CREP plus carbon offset payments in Table 6 results in little improvement over the baseline CREP scenario. Basically, CREP has extremely generous payment levels that far exceed the payments for carbon offsets. Table 7 creates a comparison for CREP baseline and carbon offset payments for a representative "average" landowner installing forest buffers. For CREP, the average landowner has a SRR of $77 per acre (Figure 6), resulting in an average annual payment of $231 per acre (3 times SRR). When considering annual payments at $231 per acre for a 15-year forest buffer, this is equivalent to the present value of $2,932 per acre. CREP also pays for the full installation costs that has a statewide average of $2,100 per acre for forest buffers (Price, Hollady, and Wainger 2019), plus the $1,000 signing bonus. In comparison, the carbon offset payments under the RGGI trading program pays $35 per C ton. The average landowner with a forest buffer has sequestration at 0.38 C tons per acre (Figure 5), yielding annual payments at $13 per acre. The present value is equivalent to $170 per acre for the 15-year forest buffer contract. Carbon offset programs also do not compensate for the installation costs or provide additional signing bonus payments. Moreover, carbon trading has barriers and transaction costs that would diminish agricultural landowner incentives to participate, similar to those that affect landowners' willingness to participate in water quality trading. As noted above, the forest carbon modeling only accounts for aboveground forest sequestration, not belowground biomass. Yet even if the aboveground forest C levels in Figure 5 were multiplied by some factor (e.g., doubled) to account for below ground C storage, the relative comparison between CREP and carbon offsets in Table 7 would show that CREP payments far exceed those in carbon trading for forest buffers.

Table 7. CREP vs. Carbon Trading Payments under 15-Year Forest Buffer Contract

Payment ($/acre)	CREP	Carbon trading
Cost-share installation	$2,100	$0
Signing bonus	$1,000	$0
Present value of annual payments (discounted at 2.5%)	$2,932	$170
Total payments ($/acre)	$6,032	$170

Table 8 shows the policy scenarios for the grass buffers, assuming a 10-year contract for the baseline CREP scenario. The benefit-cost ratio is 2.43 for grass buffers under the baseline CREP scenario, which is higher than the benefit-cost ratio for forest buffers under CREP in Table 6. Hence, grass buffers typically have higher program effectiveness than forest buffers. That is, grass buffers have lower total environmental benefits than forest buffers, but the total program costs decrease by a greater amount given the lower upfront signing bonus (only $200 per acre) and lower installation costs. Installation costs for grass buffers is $330 per acre on average compared to $2,100 per acre for forest buffers (Price, Hollady, and Wainger 2019).

The main findings on policy scenarios for forest buffers (Table 6) are largely consistent when comparing policy scenarios for grass buffers (Table 8). First, the "upfront payments" scenario creates a significant increase in landowner participation at 14.6% for grass buffers, which is more than double the 6.0% participation rate under the CREP baseline. Second, the "shorter contract length" has the lowest benefit-cost ratio amongst all scenarios in Table 8. The grass buffers with a 5-year contract has fewer years for the landowner to provide environmental benefits. Third, the "targeted bonus payments" scenarios has the highest benefit-cost ratio, suggesting that it provides the best program effectiveness. To clarify, the scenario on CREP plus carbon offsets is not included in Table 8 because the carbon sequestration model is only available for forest buffers, not grass buffers.

Table 8. Policy Scenarios for Grass Buffer Program Performance

	Baseline CREP	**All payments upfront**	**Shorter contract lengths**	**Targeted bonus payments**
Participation rate				
% of landowners	6.0%	14.6%	4.9%	5.7%
Total benefits and costs ($ in millions)				
Total benefits	0.427	1.037	0.173	0.410
Total costs	0.176	0.437	0.090	0.165
Net benefits	0.252	0.600	0.083	0.245
Benefit/cost ratio	2.43	2.37	1.92	2.48
Benefit decomposition (% of total benefits)				
Nitrogen benefits	92%	93%	92%	92%
Phosphorus benefits	8%	7%	8%	8%
Carbon benefits*	NA	NA	NA	NA

Note: There are no C benefits included for grass buffers, in contrast to Table 6 for forest buffers with aboveground biomass.

Conclusions

Several policy relevant results have emerged from our analysis to examine alternative buffer incentive programs. First, when incentive payments are made as a single upfront payment in lieu of annual payments, both participation rates and program net benefits increase significantly, relative to the CREP baseline scenario. Our analysis reveals that farmers have a strong preference for upfront payments, and offering a buffer incentive program designed around providing all payments upfront can significantly boost participation in riparian buffer programs and enhance environmental benefits. Second, when the policy scenario offers shorter contract lengths, the participation rates increase slightly relative to the CREP baseline scenario. However, the reduced contract length also significantly reduces the net environmental benefits relative to program costs. Basically, the landowner provides much lower environmental benefits because the number of years in the contract has decreased dramatically. These two findings have important implications for Maryland's CBI. Our findings suggest that the change to upfront payments is a major improvement compared to CREP. The upfront payment has increased both participation and net program benefits. Conversely, shorter contract lengths undermine the program net benefits since they have a minor effect on participation rates, but simultaneously decrease the number of years that the farmer is required to have the conservation buffer.

When examining the policy scenario with spatially varying signing bonuses based on nitrogen reduction potential, there are improvements in participation rates and net benefits relative to the CREP baseline scenario. Adjusting the signing bonus payments to reflect site-specific environmental benefits allows for greater program effectiveness, relative to the baseline CREP scenario. Ultimately, this targeting scenario provides a simple approach to improve buffer program design, as CREP currently does not include environmental benefits in the selection criteria.

Lastly, our analysis reveals that carbon offset markets will have a minimal impact on participation rates and net program benefits, relative to the CREP baseline scenario. The reason is that CREP is a very generous program compared to payments for carbon offsets. For instance, the forest buffer incentives under CREP pay for the full installation costs, signing bonus at $1000 per acre, and annual payments at three times the SRR for a 15-year contract period. The carbon sequestered for a forest buffer for the same contract period is then assumed to be paid based on the RGGI transaction prices. This amount for carbon offsets under RGGI is small in comparison to the generous CREP incentives (Table 7), where the latter has only become more generous over time. Our results suggest that carbon markets will have a minor influence on enhancing widespread riparian buffer adoption. Additionally, carbon markets have the same barriers and transaction costs, which has impeded market activity in water quality trading in Maryland for agricultural landowners. That said, carbon markets may be beneficial for other agricultural best management practices. More research is needed to provide integrated economic and environmental analysis for other practices and incentive programs.

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