**Cost of reducing nutrients from riparian buffers  
in western Maryland**

***Online Appendix***

*Key words:* costs of nutrients reduction, cost effective, riparian buffers

JEL Classification: Q15, Q52

***Supplementary Material***

This document contains supplementary material that is referenced in the main text. It contains 2 sections:

Section S1. Description of methods used in the synoptic study to identify nutrient reduction rates of existing riparian forest buffer.

Section S2. Study comparisons of cost effectiveness of nutrient reductions on riparian buffers in the Chesapeake Bay watershed.

**Section S1. Description of methods used in the synoptic study to identify nutrient reduction rates of existing riparian forest buffer.**

Two synoptic studies were performed within the Ridge & Valley (R&V) physiographic province in two counties within western Maryland (Allegany and Washington counties). Studies were conducted using high-resolution topography data and Light Detection and Ranging (LiDAR) derived digital elevation models (DEMs) with 1 to 2 m pixel resolution to define the riparian area.

Study 1 selected stream reaches with and without riparian forest buffers throughout the two counties. Stream reaches with riparian forest buffers included natural and those deliberately planted through CREP. Study 2 focused on four subwatersheds within the two counties that had a wide range of percent forested riparian areas along their mainstems and tributaries, where some riparian forests were implemented under CREP. The synoptic study included the subwatersheds’ entire mainstems from headwaters to the final outlet and all incoming tributaries and springs.

Instantaneous streamflow measurements and ‘grab’ samples were collected at the upstream and downstream ends of the stream segments and, for Study 2 only, near the downstream end of a spring or tributary before discharging into the mainstem. The downstream sites along the mainstem were before the spring/ tributary confluences. Study 1 was conducted in spring 2014 and Study 2 was conducted during two spring seasons (2016 & 2017) and one fall season (2016). All measurements and samples were collected during baseflow conditions.

Streamwater “grab’ samples were analyzed for nitrate-N (NO4-N), ammonium-N (NH4-N), total dissolved nitrogen (TDN), orthophosphate-P (PO4-P), and total dissolved phosphorus (TDP) in mg/L.

Nutrient concentrations of net lateral (lat) inflow (*C*lat) (or the groundwater contribution) of each stream reach were quantified using a steady-state reach mass balance model that neglects in-stream nutrient processing:

(1) ,

where is volumetric discharge from the instantaneous streamflow measurement, is the concentration of the respective dissolved constituent measured from the streamwater grab samples, and the subscripts , , , and refer to downstream, upstream, tributaries, and karst springs, respectively. By subtracting the quantified nutrient concentrations of upstream sites, tributaries, and karst springs from the downstream sites, we were able to estimate the contribution of nutrient concentrations in the groundwater to each stream segment during baseflow conditions.

was quantified for gaining reaches only (*Qlat*>0), which was determined by:

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Using the linear regression model, we combined all gaining reaches from Studies 1 and 2 and eliminated outliers until all assumptions were met using the global validation of linear model assumptions using the gvlma package in R (Peña and Slate 2006). Once outliers were removed from the dataset, the linear regression model was rerun, and the process iterated until all assumptions were met to find an accurate constant rate that represents nutrient decline in groundwater per increase in percent forested area. The final linear regression model included 76 data points and was used to predict nutrient loads for each individual site that was retained in the dataset using a zero and 100% riparian buffer scenario. Estimated nutrient loads from catchments with zero percent buffer were calculated by multiplying the intercept by their measured net lateral groundwater discharge (m3s-1). Loads were converted to lbs/acre-yr by dividing by the total riparian area. The median was found using Microsoft Excel’s Descriptive Statistics Tool (2021) of the computed instantaneous nutrient loads to represent annual riparian buffer nutrient reduction.

We used the median value because the nutrient load retention and measured net discharge was right-skewed, which resulted in a mean much higher than the median. Based on USGS stream gauge data, the median discharge rate was similar to the mean long-term runoff rate of Town Creek Watershed, a watershed in which many of our sites were located, which served as validation.

A significant Spearman Rank Correlation result provided confidence that a relationship existed between nutrient loads and percent forest buffers. By using the linear regression model and removing the outliers, riparian buffers are assumed to be functional and not controlled by unique and complex hydrogeomorphological conditions.

**Section S2. Study comparisons of cost effectiveness of nutrient reductions on riparian buffers in the Chesapeake Bay watershed. *Table S1.*** *Cost Effectiveness of Nutrients Reduction Comparisons from Selected Studies on Riparian Buffers in the Chesapeake Bay*

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Reference | Region, State, County | Cost Methods | Year dollars | CBWM Phase | Dis-count | BMPa | Nb load reductions, lbs acr/yr | Pb load reductions, lbs acr/yr | Cost Effectiveness | |
| S/N lb reduced/yr | S/ P lb reduced/yr |
| Bonham et al. (2006) | Farm-specific VA; multirepresenta-tive scenario without location | Model analytic approach,  FARM-PLAN. | 2006 | – | – | Buffer | – | 0.2c | – | $961/ FSS  $39/ MS |
| Wieland et al. (2009) | MD, geographic provinces & geological types | Constructed annual cost comprised of average itemized establishment cost, incentives, and rental payments. | 2007 | 5 | 5% | RGB | 20.3-45.3 | – | $1.67-$6.76 | – |
| RFB | 22.1-50.0 | – | $1.57-$6.79 | – |
| Jones et al. (2010) | Chesapeake Bay (CB) | Summary of costs from number of studies. | – | 5 | – | GB | $ | – | $3.2 | – |
| Van Houtven et al. (2012) | CB | Constructed annualized cost comprised of capital cost, O&M, opportunity & transaction costs. | 2010 | 5 | 7% | GB | NA | NA | Below $50 | Below $600 |
| FB | NA | NA | Below $100 | Below $1000 |
| Fleming et al. (2019) | CB, PA,  Lancaster County | Constructed annualized implementation costs: sum of establishment cost, maintenance cost, and opportunity cost. | 2019 | 6 | 2% | RGB | 42.7 | 0.7 | $12.2 | $2,442.2 |
| RFB | 42.7 | 0.7 | $12.9 | $1,283.7 |
| Siemek et al. (2023) | CB, MD,  Allegany County & Washington County | Constructed as present value of annual total economic cost comprised of establishment cost, maintenance cost, opportunity cost, cost-share & rental payments, and incentives. | 2019 | 6 | 5% | RGB | 21.9 & 31.1 | 0.09 & 0.2 | $12.3 & $12.0 | $2,989.0 & $1,863.4 |
| RFB | 27.8 & 38.8 | 0.4 | $20.7 & $17.6 | $1,222.1 & $1,426.0 |
| Existing RFB | 57.3d | – | $5.9 & $6.9 | – |

a RGB- riparian grass buffer, RFB -riparian forest buffer, GB-grass buffer, FB-forest buffer. b N-Nitrogen, P-Phosphorus.   
c P loads reductions are based on GIS and constructed phosphorus (P) delivery index. d Nitrogen reduction estimates are from our synoptic studies.  
 Abbreviations: CBWM- Chesapeake Bay Watershed Model, FSS-farm specific scenario, MS- multirepresentative scenario, O&M - operations & maintenance costs, NA - Not Available.

**References**

Bonham, J. G., D. J. Bosch, and J. W. Pease. "Cost-Effectiveness of Nutrient Management and Buffers: Comparisons of Two Spatial Scenarios." Journal of Agricultural and Applied Economics 38,1(2006):17–32.

Fleming, P.M., D.J. Merritts, and R.C. Walter. "Legacy Sediment Erosion Hot Spots: A Cost-Effective Approach for Targeting Water Quality Improvements. " Journal of Soil and Water Conservation 74 (2019):67A- 73A.

Jones, C., E. Branosky, M. Selman, and M. Perez. “How Nutrient Trading Could Help Restore the Chesapeake Bay.” Working Paper, World Resources Institute, Washington, DC. 2010.

Peña, E. A., and E. H. Slate. “Global validation of linear model assumptions.” Journal of the American Statistical Association 101(2006):341–354.

Siemek, S., O. Kucher, and K. N. Eshleman. "Cost of reducing nutrients from riparian buffers in western Maryland." Working Paper, 2023.

Van Houtven, G., R. Loomis, J. Baker, R. Beach, and S. Casey. “Nutrient Credit Trading for the Chesapeake Bay: An Economic Study.” Prepared for the Chesapeake Bay Commission, Annapolis, MD, 2012.

Wieland, R., D. Parker, W. Gans, and A. Martin. Costs and Cost Efficiencies for Some Nutrient Reduction Practices in Maryland. Prepared for National Oceanic and Atmospheric Administration Chesapeake Bay Office and Maryland Department of Natural Resources, 2009.