AWRA 2008 SUMMER SPECIALTY CONFERENCE
Virginia Beach, Virginia
June 30-July 2, 2008

USING SOIL SURVEYS TO TARGET RIPARIAN BUFFERS IN THE CHESAPEAKE BAY WATERSHED

Michael G. Dosskey*

ABSTRACT: The efficacy of vegetative buffers for improving water quality could be enhanced by distinguishing differences in buffer capability across watersheds and accounting for them in buffer planning. A soil survey-based method was applied to riparian areas in the Chesapeake Bay watershed. The method is based on soil attributes that are important in determining buffer function. Farmable SSURGO soil map units were rated for the capability of a buffer to trap sediment and dissolved pollutants in surface runoff from agricultural fields and to interact with pollutants in groundwater. Area-weighted average ratings for soils within 98 ft of streams were calculated for each hydrogeomorphic region (HGMR) in the watershed and compared to published expert opinion of the relative functioning of riparian zones among HGMRs. Results using the soil survey method correlated well with expert opinion at the HGMR scale. Since the soil survey method rates riparian areas at even finer resolution, it may be useful for guiding buffer installations to specific locations where impact is likely to be greater and to avoid sites where impact is likely to be small.
KEY TERMS: groundwater, nonpoint source pollution, pollutant trapping efficiency, surface runoff, vegetative buffers

INTRODUCTION

Riparian buffers are a recommended practice for reducing nutrient and sediment loads in runoff from agricultural land. While generally regarded as an effective practice, research indicates that they will function better in some locations than in others (Walter et al., 2006). The efficacy of buffer installations and buffer programs could be improved by distinguishing differences in buffer capability across watersheds and accounting for them in buffer planning. The Chesapeake Bay watershed has been divided into eleven hydrogeomorphic regions (HGMRs) having distinctly different hydrologic patterns related to pollutant runoff (Bachman et al., 1998; Figure 1). Hydrologic patterns in these HGMRs have been interpreted by a panel of experts for the relative effectiveness of riparian buffers to remove pollutants from surface runoff and groundwater flow (Lowrance et al., 1997). A different method has been developed recently that employs soil surveys for distinguishing spatial differences in relative effectiveness of buffers to filter surface runoff and groundwater (Dosskey et al., 2006). These two methods utilize somewhat different landscape information to derive estimates of relative buffer effectiveness.

The objectives of this study were to apply the soil survey method to riparian areas in the Chesapeake Bay watershed, compare the results with expert opinion interpreted from hydrologic patterns, and to discuss the potential utility of the soil survey for evaluating spatial differences in buffer capability in the watershed.

METHOD

Study Area

The Chesapeake Bay watershed is located on the U.S. eastern coast and covers 64,000 sq mi in 6 states (NY, PN, MD, WV, VA, DE) and the District of Columbia (Figure 1). Agricultural runoff contributes significantly to nutrient and sediment problems in the bay and riparian buffers are recommended throughout the watershed for reducing pollutant runoff. General land cover and riparian characteristics of each HGMR in the watershed are presented in Table 1.

*Research Ecologist, USFS Southern Research Station, National Agroforestry Center, East Campus-University of Nebraska, Lincoln, NE 68583-0822; phone: 402-437-5178 ext 4025; fax: 402-437-5712; e-mail: mdosskey@fs.fed.us.

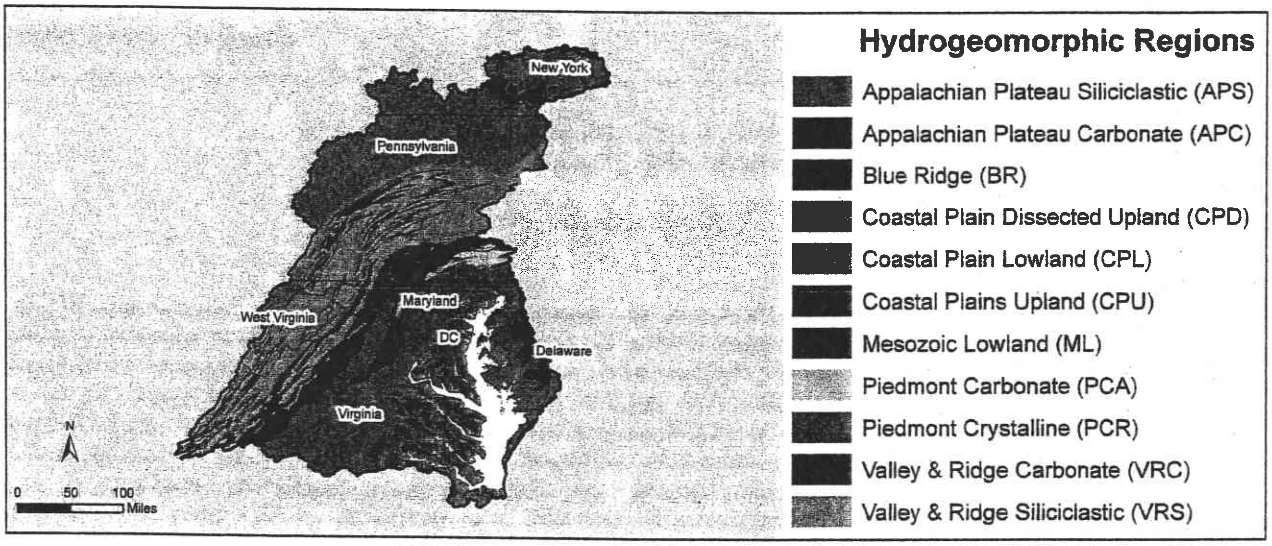

Figure 1. Hydrogeomorphic regions of the Chesapeake Bay watershed (Brakebill and Kelley, 2000).

Hydrogeomorphic Interpretations

A panel of researchers reviewed the state of knowledge about how riparian buffers function, related that knowledge to general hydrologic features of the HGMRs, and based on that information, estimated the relative potential effectiveness (high, medium, low) of buffers in each HGMR (Lowrance et al., 1997). Important hydrologic features were interpreted from landscape characteristics including land slope, soil type, and depths to water table, restrictive subsoil layers, and bedrock. The panel specifically addressed sediment and dissolved P in surface runoff and nitrate in groundwater flow. Knowledge about riparian buffer function was synthesized primarily from field studies conducted in physiographic regions represented within the watershed.

Table 1. Land cover and riparian characteristics of hydrogeomorphic regions in the Chesapeake Bay watershed. Total area and land cover percentages are from Bachman et al. (1998). Riparian area is land within 98 ft of streams identified in the National Hydrography Dataset at 1:100,000 scale (USGS, 2007). Riparian area that is rated in land capability classes 1-4 in the SSURGO soils database (NRCS, 2007) is considered to be farmable.

Region	Total Area (sq mi)	Agric. (%)	Forest (%)	Urban (%)	Riparian Area (sq mi)	Farmable Riparian Area (sq mi)	Farmable Riparian Area (%)
Coastal Plain lowlands (CPL)	4200	28	52	10	220	82	37
Coastal Plain dissected uplands (CPD)	3700	35	52	6	109	35	32
Coastal Plain uplands (CPU)	3300	33	58	9	116	39	34
Mesozoic lowland (ML)	2300	52	43	5	96	71	74
Piedmont crystalline (PCR)	10600	34	60	5	384	257	67
Blue Ridge (BR)	2500	16	83	1	80	33	41
Piedmont carbonate (PCA)	700	74	11	13	25	22	88
Valley & Ridge carbonate (VRC)	5600	52	44	4	171	110	64
Appalachian Plateau carbonate APC)	700	29	64	7	28	15	54
Valley & Ridge siliciclastic (VRS)	14950	24	74	2	507	238	47
Appalachian Plateau siliciclastic (APS)	14850	20	78	2	506	236	47

Soil Survey Interpretations

Soil survey interpretations were generated using the quantitative method of Dosskey et al. (2006). Every soil map unit in county-level soil surveys (SSURGO; NRCS, 2007) that is considered to be farmable (land capability classes 1-4) was rated for the capability of a buffer to filter pollutants from agricultural runoff. Key soil attributes include slope, surface soil texture and permeability, soil erodibility, water table depth, and hydric conditions. Only thirteen of 205 counties in the watershed did not have digitized county-level soil surveys available at the time of this assessment. Using ArcGIS (ESRI, 2006), all county soil maps were merged and, then, overlain by a stream network map (USGS, 2007; 1:100,000) and the HGMR boundary map. Area-weighted average ratings were calculated for all farmable soils within 98 ft of streams in each HGMR. Ratings were developed for sediment, dissolved pollutants in surface runoff, and groundwater interaction with the root zone. An overview of the procedure for each rating is presented below. Details are given in Dosskey et al. (2006).

For groundwater, each soil map unit was categorized according to whether or not the water table is within 6 ft of the surface at any time during a typical year and whether or not the soil is classified as hydric. The numerical rating for each HGMR is the percentage of farmable riparian area in which the water table gets shallower than 6 ft or is hydric. This categorical model indicates the areal extent of groundwater interaction with the plant root zone under farmable riparian land.

For sediment, a numerical factor was calculated for each map unit using an empirical equation based on Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997) variables and a soil texture attribute developed from information provided in the soil survey. Then, a calibration equation was used to convert that factor into an estimate of sediment trapping efficiency of a reference buffer (40 ft-wide) on that soil under reference conditions (uniform runoff from a 656 ft-wide tilled field during a 2-yr return frequency, 24-hr rainfall event). The calibration equation was determined by employing the process-based Vegetative Filter Strip Model (VFSMOD; Munoz-Carpena and Parsons, 2000). Sediment trapping efficiency is the percentage of sediment entering from an adjacent field that would be deposited in the buffer zone. The rating for each HGMR is the area-weighted average percentage for all farmable riparian area.

For dissolved pollutants in surface runoff, infiltration of runoff water was used a surrogate. Infiltration was modeled by a similar process as for sediment, except the numerical factor was calculated from a different set of RUSLE variables and a soil permeability attribute. The calibration equation converted the numerical factor into an estimate of water trapping efficiency of the reference buffer under reference conditions. Water trapping efficiency is the percentage of runoff water entering from an adjacent field that would be infiltrated in the buffer zone. The rating for each HGMR is the area-weighted average percentage for all farmable riparian area.

Method Comparison

Ratings for the HGMRs using the soil survey method were tabled and compared with corresponding published ratings based on hydrologic patterns. Comparisons and contrasts were explained in terms of similarities and differences between the two methods.

RESULTS and DISCUSSION

Hydrogeomorphic Regions

The HGMR names and boundaries differ somewhat between the two methods (Table 2). Correspondence was determined by comparing locations of map unit boundaries and by correlating descriptions of groundwater flow patterns and geology in each HGMR. The regions PCA, VRC, and APC shown in Figure 1 were considered as one region (Piedmont/Valley & Ridge limestone) by Lowrance et al., (1997) and the regions PCR and BR also were considered as one (Piedmont schist/gneiss). The CPU region in Figure 1 corresponds to the combination of Inner Coastal Plain and poorly-drained Outer Coastal Plain regions of Lowrance et al. (1997).

Table 2. Potential effectiveness of riparian buffers for nonpoint source pollution control in different hydrogeomorphic regions of the Chesapeake Bay watershed as assessed by two different methods: expert opinion interpreted from generalized hydrologic patterns (Lowrance et al., 1997) and mathematical modeling based on soil survey data (Dosskey et al., 2006).

	Soil Survey Interpretation*				Hydrogeomorphic Interpretation		
Region (Brakebill and Kelley, 2000)	Ground water (%)	Sediment (%)	Water (%)	Region (Lowrance et al.,1997)	Nitrate	Sediment	Dissolved P
Coastal Plain lowlands (CPL)	88	97	25	Outer Coastal Plain, tidal	L-M	M-H	L-M
Coastal Plain dissect uplands (CPD)	82	96	27	Outer Coastal Plain, well-drained	L	M-H	L-M
Coastal Plain uplands (CPU)	86	95	25	Outer Coastal Plain, poorly-drained	M-H	M-H	L-M
				Inner Coastal Plain	H	M-H	L-M
Mesozoic lowland (ML)	88	95	20	Piedmont, thin soil, Triassic shale	H	M-H	L-M
Piedmont crystalline (PCR)	73	92	20	Piedmont schist/gneiss	M	M-H	L-M
Blue Ridge (BR)	66	94	23				
Piedmont carbonate (PCA)	71	93	19	Piedmont/Valley & Ridge limestone	L	M-H	L-M
Valley & Ridge carbonate (VRC)	66	94	21				
Appalachian Plateau carb. (APC)	84	90	18				
Valley & Ridge siliciclastic (VRS)	76	95	22	Valley & Ridge sandstone/shale	M-H	M-H	L-M
Appalachian Plateau silicic. (APS)	81	93	21	Valley & Ridge/ Appalachian	M-H	M-H	L-M

* Groundwater: percentage of farmable riparian area in which the water table gets shallower than 6 ft or is hydric. Sediment and Water: area-weighted average trapping efficiency for all farmable area expressed as a percentage of the sediment or water load entering from an adjacent field under reference conditions.

Groundwater

Hydrologic interpretations of nitrate removal from groundwater yielded substantial differences among regions (Table 2). High ratings are given to HGMRs having shallow groundwater, moderate slope, and a shallow aquitard (clay on Coastal Plain, bedrock in other HGMRs) that confines greater flow close to the soil surface. These conditions promote nitrate flow into the riparian zone and greater nitrate removal by riparian vegetation and denitrification in the root zone. Lower ratings are given for HGMRs having flatter terrain and/or deeper or absent aquitard.

Soil survey interpretations indicate there is a high percentage (66-88%) of farmable riparian soils in all HGMRs where groundwater may interact with the root zone (Table 2). Percentages were somewhat higher for Coastal Plain and Mesozoic lowland HGMRs. The soil survey method produces less apparent separation between HGMRs than the hydrologic interpretations. However, a plot of corresponding results shows fairly good agreement between the two methods (Figure 2). The major departures were for the Coastal Plain HGMRs, CPD and CPL, that do not have a shallow confining layer. For the other HGMRs, good agreement probably reflects a positive correlation between the areal extent of shallow groundwater and the presence of shallow aquitards. The soil survey method could be improved by accounting for presence of low-permeability strata, but soil surveys lack information about important features that are deeper than 6 ft.

Sediment and Dissolved Pollutants

Hydrologic interpretations indicate that buffer effectiveness for sediment and dissolved P do not differ significantly between regions (Table 2). Sediment deposition is always higher (M-H) than dissolved P retention (L-M). Low ratings for dissolved P are attributed mainly to low infiltration on steep, fine-textured soils (Piedmont and mountainous HGMRs) or high infiltration into low P-fixing soils (sandy soils in Coastal Plain HGMRs).

Soil survey interpretations also indicate that sediment deposition and water infiltration do not differ significantly among HGMRs, although both trend higher on the Coastal Plain. The sediment ratings are all very high (90-97%) and water infiltration ratings are all quite low (18-27%). Such low values for water infiltration on the Coastal Plain (25-27%) were not expected since low slopes and sandy soils should promote high infiltration. Uniformity of the ratings among HGMRs may be due partly to relative similarity of slopes and soil textures of farmable soils on alluvial floodplains despite major differences among HGMRs in upland physiography and soils.

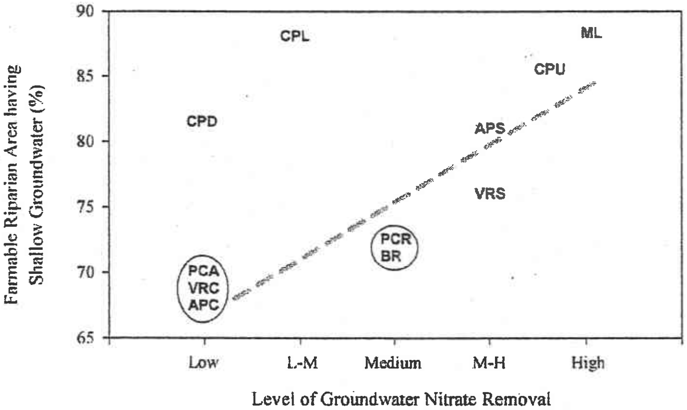

Figure 2. Relationship between expert opinion of the level of groundwater nitrate removal by riparian areas in each hydrogeomorphic region and the corresponding soil survey result for percentage of farmable riparian area where the soil is hydric or the water table is within 6 ft of the surface at some time during the year.

Potential Use of Soil Surveys to Target Riparian Buffers

The soil survey method produced similar results as the hydrologic interpretations at the HGMR scale. Both methods ranked HGMRs similarly for sediments and dissolved pollutants in surface runoff. Both methods distinguished differences between HGMRs in effectiveness for buffering groundwater, although the soil survey method might be improved by including information on subsoil strata. General agreement between expert opinion and soil survey methods probably confers some validity on both methods.

An important advantage of the soil survey method is that it can be applied at finer scales than HGMRs. The method begins by rating soil survey map units and, then, aggregates upward to produce average ratings for each HGMR. Ratings may be aggregated to other scales, such as to compare sub-watersheds or counties. The ratings for individual soil map units may be used directly for site-scale planning by enabling the ranking of sites based on potential level of impact. Individual map units are delineated to sizes as small as one acre. Since, the soil survey method rates only farmable soils using objective methods, it can support buffer planning for the Conservation Reserve Program (CRP) and related other programs which enroll land into buffers that currently is being cultivated.

CONCLUSIONS

The soil survey method ranked HGMRs for pollutant reduction functions of riparian buffers similarly to rankings based on expert interpretation of generalized hydrologic patterns. Good agreement may indicate general validity of both methods. The soil survey method can also be applied at smaller scales than HGMRs and may support site-scale planning and targeting of riparian buffer installations under CRP and related programs.

ACKNOWLEDGMENTS

The author thanks Todd Kellerman and Richard Carman at the National Agroforestry Center for providing GIS support for this study.

REFERENCES

Bachman, L.J., B. Lindsey, J. Brakebill, and D.S. Powars, 1998. Ground-Water Discharge and Base-Flow Nitrate Loads of Nontidal Streams, and their Relation to a Hydrogeomorphic Classification of the Chesapeake Bay Watershed, Middle Atlantic Coast. Water-Resources Investigations Report 98-4059. U.S. Geological Survey, Denver, CO.

Brakebill, J.W., and S.K. Kelley, 2000. Hydrogeomorphic Regions of the Chesapeake Bay Watershed (ver. 1). Water-Resources Investigations Report 00-424. U.S. Geological Survey, Washington, D.C.

Dosskey, M.G., M.J. Helmers, and D.E. Eisenhauer, 2006. An Approach for Using Soil Surveys to Guide the Placement of Water Quality Buffers. Journal of Soil and Water Conservation 61:344-354.

Environmental Systems Research Institute (ESRI). 2006. ArcGIS Version 9.2. ESRI, Redlands, California.

Lowrance, R., L.S. Altier, J.D. Newbold, R.R. Schnabel, P.M. Groffman, J.M. Denver, D.L. Correll, J.W. Gilliam, J.L. Robinson, R.B. Brinsfield, K.W. Staver, W. Lucas, and A.H. Todd, 1997. Water Quality Functions of Riparian Forest Buffers in Chesapeake Bay Watersheds. Environmental Management 21:687-712.

Muñoz-Carpena, R., and J.E. Parsons. 2000. VFSMOD, Vol. 1.04, User's Manual. North Carolina State University, Raleigh.

Natural Resources Conservation Service (NRCS), 2007. Soil Survey Geographic Database (SSURGO 2.2). USDA-NRCS, Washington, D.C. Available at http://soildatamart.nrcs.usda.gov; last accessed October 2007.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder (coordinators), 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703. U.S. Department of Agriculture, Washington, D.C.

U.S. Geological Survey (USGS), 2007. The National Hydrography Dataset. U.S. Department of Interior and U.S. Environmental Protection Agency, EROS Data Center, Sioux Falls, South Dakota. Available at http://edcwww.cr.usgs.gov/products/map/dlg.html#samples; last accessed October 2007.

Walter, T., M. Dosskey, M. Khanna, J. Miller, M. Tomer, and J. Wiens, 2007. The Science of Targeting within Landscapes and Watersheds to Improve Conservation Success. P. 63-89 In: M Schnepf and C. Cox (eds.) Managing Agricultural Landscapes for Environmental Quality: Strengthening the Science Base. Soil and Water Conservation Society, Ankeny, IA.