DEFINING STREAMSIDE MANAGEMENT ZONES OR RIPARIAN BUFFERS

Thomas M. Williams, Donald J. Lipscomb, and Christopher J. Post[1]

Abstract—Forestry Best Management Practices (BMPs) have been highly successful in protecting water quality throughout the Southeast. Numerous studies have found them to be effective in protecting water quality. Despite being mostly voluntary, compliance is generally about 90 percent across the region. Streamside Management Zones (SMZs) or riparian buffers are specified for perennial streams in all of the southeastern BMP manuals, and buffer width generally increases with land slope. However, that is where the similarity ends. Each State has specified different buffer widths in a variety of methods. For example, a creek with a side slope of 40 percent requires a 120-foot buffer in South Carolina but the same stream would require a 50-foot-wide buffer in Mississippi. We compared the various State specifications of SMZ on stream networks from watersheds in northwestern South Carolina, including three on the Clemson Experimental Forest where we evaluated South Carolina's BMPs. We also tested methodologies on an independent watershed in north Georgia. We found guideline differences consistent between watersheds and watershed differences consistent between guidelines. Size of SMZ was more influenced by drainage density than side slope, despite the explicit use of side slope in the guidelines. There was no entirely satisfactory way to map SMZ areas with publicly available data.

INTRODUCTION

Voluntary Forestry Best Management Practices (BMPs) have been successful in protecting water quality throughout the Southeast (Shepard 2002). A variety of studies during the 1960s to 1980s evaluated water-quality impacts of forestry practices (Beasley 1979, Dickerson 1975, Douglass and Goodwin 1980, Hewlett 1979, Hewlett and Douglass 1968, Neary and others 1986, Riekerk 1983, Ursic 1975). They found several practices that contributed to sedimentation, the most common impairment to water quality caused by forestry (Yoho 1980). Forestry BMPs were then devised to eliminate those practices. A number of later studies found BMPs effective in preventing water-quality degradation noted in the earlier studies (Florida Department Of Environmental Protection 1997, Frazee 1996, Williams and others 1999). Therefore, throughout the forestry community of scientists, industry, loggers, and landowners, BMPs are seen as sufficient to protect water quality. Monitoring programs have shown that there is a high degree of compliance with these voluntary programs.

Voluntary BMP compliance results in substantial cost savings to the public. Kilgore and others (2002) estimated that compliance monitoring in the Eastern United States cost an average of $60,000 per year in States with voluntary programs, compared to $500,000 to $700,000 per year for States with regulatory programs. Western States spend even more on regulatory programs, averaging over $1 million per year. BMPs do have a considerable private cost to forest landowners. Cubbage and others (2002) reviewed costs of BMP compliance and showed Streamside Management Zones (SMZ) had small direct costs (< 10 percent of total BMP cost) but high opportunity costs. On U.S. Forest Service land, the lost opportunity for management of SMZ land was estimated as 26 percent of sale revenue. They also reported an estimated SMZ opportunity cost of $2,530 per acre in Arkansas. All States have an SMZ recommendation, which varies in width by land slope (table 1). Opportunity costs of compliance with recommended SMZ width will vary considerably. In order to plan management activity, it would be very useful to have an accurate planning map of SMZ width.

During the last 3 years, we have developed an ARC/INFO AML program to map variable width SMZ areas (Lipscomb and Williams 2000, 2002; Williams and others 2003). This

Table 1—Widths (feet) of SMZ recommended in several Southeastern United States forestry BMP manuals[a]

Slope percent	0	10	20	30	40	50	60
VA[b] (warm)	50	50	50	50	50	50	50
VA[b] (cold)	65	65	70	100	100	125	125
VA[b] (DW)	100	150	150	150	200	200	200
NC[c] (warm)	50	50	50	50	50	50	50
NC[c] (cold)	50	65	70	100	100	125	125
SC[d] (warm)	40	80	80	120	120	160	160
SC[d] (cold)	40	120	120	160	160	200	200
GA[e]	40	40	40	70	70	100	100
TN[f]	25	45	65	85	105	125	145
KY[g]	25	45	65	85	105	125	145
MS[h]	30	40	40	50	50	60	60

SMZ = streamside management zones; BMP = best management practices; warm = warm water fishery; cold = cold water fishery; DW = drinking water supply.
[a] Width for the outer edge of the zone of minimal soil disturbance on one side of the stream.
[b] Virginia Department of Forestry (1997).
[c] North Carolina Division of Forest Resources (1989).
[d] South Carolina Forestry Commission (1994).
[e] Georgia Forestry Commission (1999).
[f] Tennessee Division of Forestry (1993).
[g] Springer and Perkins (1997).
[h] Mississippi Forestry Commission (2000).

[1]Professor, Baruch Institute of Coastal Ecology and Forest Science, Clemson University, Georgetown, SC 29634; and Research/Demonstration Forester and Assistant Professor, Department of Forest Resources, Clemson University, Clemson SC 29634, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

program maps the SMZ width on each side of the stream, dependent on the slope, as defined in the BMP manuals. We have used the program to evaluate differences in SMZ width on a series of watersheds in the Piedmont of South Carolina and Georgia. Here we will present the differences found and examine limitations in mapping SMZ widths.

METHODS AND RESULTS

Phase 1. Comparison of State Guidelines

Methods—The first section of the study was to evaluate differences in Southeastern State guidelines. For this phase, we utilized five watersheds in western South Carolina. Four of the watersheds were small experimental watersheds on the Clemson Experimental Forest (34°44'50"W 82°52'27"N) used in a prior study testing the South Carolina Forestry BMPs. Williams and others (1999) described the soils, vegetation, and treatments on these watersheds. In general, they are small watersheds (97 to 165 acres) with steep slopes (table 2). For each watershed, streams were mapped from 1:12,000 photographs and field checked; contour lines were digitized from 1:24,000 quadrangle maps and converted to a Digital Elevation Model (DEM) with a cell size of 40 by 40 feet. The fifth watershed, Three and Twenty Creek, located southeast of Clemson, SC (34°35'59"N 82°44'19"W) was considerably larger (59,000 acres) and was designated by the U.S. Geological Service (USGS) Hydrologic Unit Code 03060101-100. On this watershed, streams were hand digitized from USGS quadrangle maps to include all blue lines (either solid or dotted). A DEM with 40- by 40-foot grid cells was developed for this watershed in the same manner as for the four smaller watersheds.

Each of the five watersheds was then analyzed with the ARC/INFO AML program to map SMZ widths (Lipscomb and Williams 2002). The program utilizes the DEM to calculate the right and left side slope on 40' sections of the stream. These slopes are then put into slope classes as defined in the various BMP manuals; that is, the slope classes in table 1 are used to define an SMZ width for that section and side of the stream. These are combined for all sections of the stream, and an SMZ area is mapped. The SMZ area was determined for guidelines from Georgia, Kentucky, Mississippi, North Carolina, and South Carolina. Tennessee and Virginia were mapped but are not presented since they are the same as Kentucky and North Carolina, respectively. SMZ area was then standardized as percentage of total watershed area.

Table 2—Distribution of land slopes in the four study watersheds used for BMP evaluation

Slope categories	0–5	5–20	20–40	> 40
	- - - - - - - - -	*percent*	*- - - - - - - -*	
Watershed				
Kenamore One	9.4	17.1	55.1	18.4
Kenamore Two	10.2	9.7	47.7	32.4
Ramsey Bridge	16.8	12.4	53.8	17.0
Holly Springs	12.3	26.7	46.5	9.3

BMP = best management practices.
All slopes were calculated from contours extracted from USGS quadrangle maps.

Results—Application of each State SMZ guidelines to the same watersheds reveals a number of variations. The ways each State deals with slope differs (table 1). Although Mississippi generally requires the least in streamside management zone and South Carolina the most, the relative ranking changes with slope. Kentucky and Tennessee have small requirements at slight slopes but the requirement increases steadily. Kentucky has a different width for every 5-percent change in slope, Tennessee has a different width for every 10-percent change in slope, whereas South Carolina and Mississippi use 0 to 5 percent, 5 to 20 percent, 20 to 40 percent, and over 40-percent groupings. Georgia is slightly different, and North Carolina and Virginia only have slope differences in their cold water fishery guidelines. All the States agree SMZ width should increase with slope, but each State has a different interpretation as to the best way to group slope classes.

Differences in the State guidelines interact with the topography of individual watersheds (table 3). In general, differences in State guidelines are consistent between watersheds, with South Carolina always specifying the greatest area and Mississippi the least. Also the percentage of watershed in SMZ increases with the percentage of steep slopes on the watershed. Kenamore Two, with over 80 percent of the watershed at slopes greater than 20 percent, has the greatest percentage of watershed in SMZ, regardless of which State guidelines are used. Kentucky shows the widest variation between watersheds with SMZ, representing 10.5 percent of Holly Springs and 20.0 percent of Kenamore Two.

However, the differences in SMZ area are not primarily due to differences in side slope. Table 4 standardizes SMZ width by stream length rather than watershed area. In this case an overall average SMZ width characterizes the watersheds and BMP differences. The North Carolina values demonstrate rounding errors and variations in the program because the NC guidelines specify a uniform 50-foot width. When standardized by the length of stream there is no difference between the watersheds for most of the different State BMP guidelines. Kentucky is an exception because it has much narrower slope categories than the other States. The required SMZ changes for every 10-percent change in slope in the Kentucky guidelines, whereas the required SMZ width is the same over 20 percent or more classes in the other States. The total area in SMZ is more heavily influenced by length of stream than by the slope of the watershed.

The Three and Twenty watershed was added as a test of the technique on a larger watershed. It is similar to the four forested watersheds but represents the smallest watershed normally mapped by EPA in water-quality assessment, which are watersheds designated by an 11-digit number of the USGS Hydrologic Unit Code. This is the smallest normal level of watershed delineation in publicly available GIS data. The SMZ on Three and Twenty Creek was calculated from GIS data that was publicly available for the stream.

Table 3—Variation in size of Streamside Management Zone (SMZ) calculated from specifications in Southeastern U.S. forestry best management practice guidelines

Watershed data	Kenamore One	Kenamore Two	Ramsey Bridge	Holly Springs	Three and Twenty
Size (*acres*)	104	91	144	167	59,000
Georgia	10.1 (9.7)	16.0 (17.6)	19.0 (13.2)	16.5 (9.7)	1,767 (3.0)
Kentucky	11.3 (10.9)	18.2 (20.0)	20.5 (14.2)	17.6 (10.5)	1,22 (2.1)
Mississippi	9.4 (9.0)	14.9 (15.9)	17.6 (12.2)	15.3 (9.2)	1,380 (2.4)
North Carolina	12.3 (11.8)	19.3 (21.2)	23.5 (16.3)	20.4 (12.1)	2,177 (3.7)
South Carolina	21.9 (21.0)	32.8 (36.0)	40.1 (27.8)	35.0 (20.1)	2,560 (4.3)

SMZ = streamside management zone.
All sizes are in acres and represent the total area contained in both primary and secondary SMZ. Numbers in parentheses are percents of total watershed area.
All data were generated by ARC/INFO AML using distances specified in each State's guidelines.
Data for Virginia is identical to North Carolina, and Tennessee is identical to Kentucky, so these States are not shown. Warm water fishery guidelines were used in each case.

Table 4–Variation in overall average width of Streamside Management Zone calculated following specifications in Southeastern U.S. forestry best management practice guidelines

Watershed	Kenamore One	Kenamore Two	Ramsey Bridge	Holly Springs	Three and Twenty
Stream length (*feet*)	5,343	8,393	9,040	10,250	952,565
Georgia	41.2	41.5	40.4	39.7	40.2
Kentucky	46.0	48.8	43.6	42.4	27.9
Mississippi	38.3	38.7	37.4	36.9	31.5
North Carolina	50.1	50.1	49.9	49.2	49.8
South Carolina	85.3	85.2	85.2	84.3	58.5
Stream density (*feet per acre*)	51.2	92.3	71.0	54.0	16.1

SMZ = streamside management zone.
All widths are for one side of the creek and represent the total width of both primary and SMZ. Data source is same as Table 3. Average width was calculated by dividing total SMZ area by stream length.

There is a large difference in the proportion of Three and Twenty Creek watershed mapped as SMZ compared to the four experimental watersheds (table 3). Some of the difference can be attributed to flatter slopes on the larger watershed as can be seen in the narrower average width for Kentucky and South Carolina in table 4. However, much of the difference is attributable to stream length, represented by the drainage density term in table 4. Drainage density is expressed in feet of stream length per acre of watershed area. It is clear that the publicly available data does not represent as many streams in the larger watershed.

Each of the State BMP manuals has criteria to determine the extent of perennial (and in some cases intermittent) streams where an SMZ is recommended. The streams on the four experimental watersheds were mapped according to the South Carolina Guidelines. The streams of the Three and Twenty watershed were mapped only from the USGS "blue lines". It seems quite clear that these data do not represent length of streams specified by the ground criteria.

PHASE 2. Techniques to Delineate Stream Length Appropriate to State Guidelines

Methods—The second phase of this study sought to examine methods for estimating the area included in SMZ from public data that are more accurate than the present "blue lines". A model watershed was chosen in the Chattahoochee National Forest in northern Georgia. This was a 3,960-acre watershed in the Jacks Gap Quadrangle (34°49'57"N 89°49'00"W). Data collected for this watershed consisted of three publicly available sources. Contours were taken from the Jacks Gap Quadrangle map, as were the "blue line" streams, and from panchromatic Digital Ortho Quarter Quads. All data were then rectified to the same coordinate system (Georgia West State Plane, North American Datum 1927). Contour lines were then used to create a DEM as described in phase one. Two techniques were evaluated to estimate stream lengths: Strahler valley orders and stream generation from DEM.

Two criteria were used to determine the smallest valley to be used with the valley order technique. A valley had to be present on three consecutive contour lines (for Jacks Gap this would represent 60 feet of down valley slope) and be at least 300 feet long. These criteria were generally evaluated at a screen resolution of 1,038 by 764 pixels with a representative fraction of 1:7,200 (1 inch = 600 feet. A line was digitized representing the lowest points on each contour line. All valley bottoms were digitized uphill beginning at a "blue line" stream or a digitized valley bottom. These lines were then cleaned and formed into continuous networks for each stream crossing the quadrangle boundaries. Digitizing was done in the uphill direction because that allowed the analyst to use a right-hand maze rule in order to digitize to all valley bottoms. Each line segment in the network was then flipped in order to make the network point down hill.

Once a network of valley bottoms was created, it was then evaluated by the Strahler (1957) Stream Order rule. This rule makes all unbranched segments first-order valleys. Where two first-order valleys merge, the valley becomes second order; two second orders merge to form a third order, etc. If a lower order stream merges with a higher order, there is no change in order. Valley order was then used to generate a series of stream networks. Each network assumed that a stream needing an SMZ corresponded to a valley of specific order. At the outlet, the valley was a fifth order, allowing evaluation of first through fourth order. An SMZ was then assigned to each stream network using the AML program. The North Carolina warm water SMZ definition was used in all analyses.

Stream networks can be automatically generated from a DEM. There are a series of intermediate steps that create grid data in a given sequence. The first step is to make sure there are no closed depressions, called sinks, in the DEM. A filter of the DEM is run a series of times that fills the closed depressions with the mean value of the grid cells surrounding it called filled sinks. A second grid, called flow direction, determines downhill direction for each grid cell. A third, called flow accumulation, determines the number of uphill grid cells for each cell. From the flow accumulation grid, a stream network can be generated in a simple manner of declaring the minimum watershed size in grid cells. For example, the analyst can specify a minimum watershed size of 1,000 grid cells, and each grid cell with more than 1,000 cells uphill will be formed into a stream network using the direction grid. For 40- by 40-foot grid cells, this would represent an area of 1,600,000 square feet or roughly 40 acres. Exactly 40 acres would be 1,089 grid cells.

We used the 40-foot grid cell DEM created for the Jacks Gap Quadrangle to create grids of filled sinks, flow direction, and flow accumulation. The example watershed boundary was used to extract flow direction and flow accumulation grids containing data for only the example watershed. Stream networks were then created corresponding to 1-, 2-, 5-,10-, 20-, and 40-acre subwatersheds. These stream networks were then used to generate SMZ areas for each subwtatershed size. The North Carolina warm water SMZ definition was used for all SMZ analyses on networks determined by DEM analysis.

Results—The example watershed was chosen to be similar to the four experimental watersheds used in phase one where streams requiring SMZ protection were delineated by ground application of the BMP guidelines. It was 40 times larger than the experimental watersheds but 10 times smaller than watersheds normally evaluated by EPA. Using the above criteria for a minimum valley, the outlet was a sixth-order valley. The lengths of the fifth- and sixth-order streams were quite short, and SMZ area was determined for networks of fourth and higher to first and higher (table 5).

On this watershed, the "blue line" streams were 16.2 miles long and had an SMZ of 192 acres or 4.8 percent of the watershed. The percentage is similar to the 3.7 percent on the Three and Twenty watershed (table 3). The "blue line" values are intermediate between the values for valleys above a fourth order and a third order. The blue lines on the quad sheets appear to have used fourth-order valleys and used the original Horton (1945) definition of order, which assigns the order not to segments but to the longest tributary. In the Strahler system, a fourth-order stream extends only to the junction of the two third-order streams that form it. In the Horton system, the third-order stream extends all the way to the head of the longest tributary. Thus, the blue line "fourth-order" streams are longer than the streams defined by the Strahler method.

Using second order valleys as the limit for a perennial stream most closely approximated the SMZ delineated by field examination. For the North Carolina warm water SMZ definition, SMZ area was from 11.8 to 21.2 percent of the four experimental watersheds in phase one. SMZ area was 13.1 percent of the example watershed using a second-order valley as the minimum size of a valley with a perennial stream.

Using automated mapping of stream networks from the DEM produces similar values to the valley order technique (table 6). In this case, the "blue line" streams are best approximated by a minimum watershed slightly more than 10 acres. Likewise, the SMZ most like those on the field-checked experimental watersheds was found with a two-acre minimum watershed size.

Table 5—Results of Strahler Valley Order Method

	Blue line streams	6th	5th	4th	3rd	2nd	1st
Number of segments	164	12	37	102	159	354	711
Length of segments (miles)	16.2	0.87	2.41	6.37	10.9	23.2	74.4
SMZ (*acres*)	192			114	246	520	1,386
SMZ (*percent of watershed*)	4.84			2.88	6.20	13.1	35.0

SMZ = streamside management zones.
All valleys, more than 60 feet fall and 300 feet long, were ordered, and North Carolina SMZ was determined for networks of valleys fromfirst to fourth order. Number and length of stream segments were determined for each network of lines digitized in valley bottoms. Note the length of segments in this table isthe length of only those of the order listed. SMZ area was determined not only for those segment lengths but for lengths of all higher order valleys.

Table 6—Summary of stream lengths and SMZ areas determined by stream network calculated from DEM

	Blue line Streams	40	20	10	5	2	1
	- - - - - - - - - -	- - - - - -	- - - - - -	*acres*	- - - - - -	- - - - - -	- - - - - -
Number of segments	164	37	79	142	309	652	1,460
Length of segments (*miles*)	16.2	3.56	10.4	17.6	23.8	46.6	80.3
SMZ (*acres*)	192	168	254	336	458	659	1,007
SMZ (*percent of watershed*)	4.86	4.23	6.41	8.48	11.6	16.6	25.4

SMZ = streamside management zones; DEM = digital elevation model; BMP = best management practices.
Each network was determined by assuming a stream was formed by a minimum watershed size varying from 1 to 40 acres. All SMZ areas are for the North Carolina BMP specifications. Note the length of segments includes all segments to the outlet for each network. SMZ area was calculated based on these segments.

DISCUSSION

SMZ areas may occupy a significant portion of steeper Piedmont watersheds. Management planning would be greatly aided with a reliable method to map SMZ zones without the expense of ground mapping. However, mapping SMZ zones accurately will not be a trivial task. The size of SMZ varies considerably among the Southern States, and the size also increases rapidly in steeper terrain. The most significant factor, however, is not side slope but rather the length of streams or drainage density, which increases rapidly with increasing slope.

Mapping SMZ widths from publicly available GIS data under estimates the size of SMZ that will be determined by field mapping. Streams designated by blue lines on 1:24,000 USGS quadrangle maps are larger than those that meet field definitions of perennial streams. We examined two techniques to map streams from other public data.

Mapping valleys from contours and assigning Strahler order to valley segments produces a stream network that can approximate the field values. Using set criteria for a minimal valley of 300 feet in length and 60 feet in total elevation change allowed us to define a second-order valley as a close approximation of field delineated perennial streams. Such mapping is widely applicable as the relationship of stream length, drainage area, and stream order are well recognized (Horton 1945, Leopold and others 1964). The technique has two limitations: mapping of the valleys is done by hand digitizing and is labor intensive; and Strahler orders are limited to several discreet values (1 to 7 or 8), and stream length and number increase exponentially as order decreases.

Generation of stream networks automatically from DEMs can be done quickly. The limitation on alternatives is only the number of grid cells in the DEM. The length of stream is more closely linear to the minimum area of subwatershed. In the case studied, a 2-acre minimum most closely approximated the field data. However, this technique does not have any geomorphic basis, and the minimum may be specific to each individual watershed. We found that the two-acre minimum was not satisfactory for broad river valley segments. There, the GIS placed a number of parallel pseudo streams across the valley, incorrectly placing the SMZ across the valley bottom.

Neither of the alternative techniques was entirely successful in accurately mapping SMZs for forest management planning. Also these methods do not address the question posed by the differences in State guidelines— What SMZ is both sufficient and necessary to protect water quality?

LITERATURE CITED

Beasley, R.S. 1979. Intensive site preparation and sediment loss on steep watersheds in the Gulf Coastal Plain. Soil Science Society of America Journal. 43: 3.

Cubbage, F.; Scott, J.; Pressley, T.; Moore, S. 2002. Costs of forestry best management practices in the South: A review.

Dickerson, B.P. 1975. Stormflows and erosion after tree length skiding on coastal plain soils. Transactions of the American Society of Agricultural Engineers. 18: 867-868,872.

Douglass, J. E.; Goodwin, O.C. 1980. Runoff and soil erosion from forest site preparation practices. In: Proceedings: U.S. forestry and water quality: What course for the 80's? An analysis of environmental issues. Richmond, VA: Water Pollution Control Association: 50-74

Florida Department Of Environmental Protection. 1997. Biological assessment of effectiveness of forestry best management practices. Tallahassee FL: Bureau of Laboratories, Division of Administrative and Technical Services, Florida Department of Environmental Protection. 18 p.

Frazee, J.W. 1996. Effects of forest harvesting best management practices on surface water quality in Virginia coastal plain. MS Thesis. Blacksburg, VA: Virginia Polytechnic Institute and State University. 210 p.

Hewlett, J.D. 1979. Forest water quality: An experiment in harvesting and regenerating Piedmont forests. Athens, GA: School of Forest Resources, University of Georgia. 22 p.

Hewlett, J.D.; Douglass, J.E. 1968. Blending forest uses. Station Pap. SE-37. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 15 p.

Horton, R.E. 1945. Erosional developments of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geologic Society of America Bulletin. 56: 275-370.

Kilgore, M.A.; Ellefson, P.V.; Phillips, M.J. 2002. State BMP monitoring programs in the Eastern United States. In: Shepard J., ed. Forestry best management practices research symposium: Abstracts and presentations. CD-ROM. Gainesville, FL: National Council on Air and Stream Improvement.

Leopold, L.B.; Wolman, M.G; Miller, J.P. 1964. Fluvial geomorphology. San Francisco, CA: W.H. Freeman and Company: 138-142.

Lipscomb, D.J.; Williams, T.M. 2000. An Arc/Info program to model stream management zones (SMZ) as defined by South Carolina forestry best management practices. In: Southern Forestry GIS 2000. CD-ROM. Athens, GA: University of Georgia.

Lipscomb, D.J.; Williams, T.M. 2002. Mapping variable width, streamside management zones for water quality protection. In: Shepard J., ed. Forestry best management practices research symposium: Abstracts and presentations. CD-ROM. Gainesville, FL: National Council on Air and Stream Improvement.

Neary, D.G.; Bush, P.B.; Grant, M.A. 1986. Water quality of ephemeral forest streams after site preparation with the herbicide hexazinone. Forest Ecology and Management. 14: 23-40.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. Water Resources Bulletin. 19: 73-79.

Shepard, J. 2002. Forestry best management practices research symposium: Abstracts and presentations; 2002 April 15-17; Atlanta, GA. CD-ROM. Gainesville, FL: National Council on Air and Stream Improvement.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. American Geopyhsical Union Transactions. 36: 913-920.

Ursic, S.J. 1975. Harvesting southern forests: A threat to water quality? In: Non-point sources of water pollution. Blacksburg, VA: Virginia Polyechnic Institute and State University: 145-151.

Williams, T.M.; Hook, D.D.; Lipscomb, D.J. [and others]. 1999. Effectiveness of best management practices to protect water quality in the South Carolina Piedmont In: Haywood, J.D., ed. Proceedings of the tenth biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 271-277.

Williams, T.M.; Lipscomb, D.J.; English, W.R.; Nickel, C. 2003. Mapping variable-width streamside management zones for water quality protection. Biomass and Bioenergy. 24: 329–336.

Yoho, N.S 1980. Forest management and sediment production in the South - a review. Southern Journal of Applied Forestry. 4: 27-36.