Using Spatial Features to Review Application, Effectiveness, and Compliance of Forestry Best Management Practices in West Virginia

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ABSTRACT

The application, effectiveness, and compliance of forestry best management practices (BMPs) were assessed based on 33 randomly selected sites with streamside management zones (SMZs) in West Virginia. Application of BMPs was assessed based upon the methods and techniques of applying the BMP, while compliance was assessed based on the presence of required BMPs. Effectiveness was determined based upon the durability and longevity of an applied BMP. A series of 12 checklists were used to examine 29 BMPs on haul roads, skid trails, landings, and in SMZs. Spatial data, soil, stream type, and population density were also collected for the sites to identify how these spatial attributes affect BMP application, effectiveness, and compliance. Results indicated that higher levels of application, effectiveness, and compliance were found on sites with either intermittent or ephemeral streams, wider SMZs, or low soil moisture index; no significant differences were presented in BMP application, effectiveness, and compliance among stream type, SMZ width, soil series, moisture index, and population category. Road and landing layouts located outside of high water cumulative flow areas also contributed to higher rates of BMP application, effectiveness, and compliance, which substantiated the importance of pre-harvest planning.

Keywords: *best management practices, non-point source pollution, spatial features, timber harvesting, forest operations*

Introduction

Best management practices (BMPs) were developed to prevent or reduce the adverse impacts of forest management activities on water quality while permitting the intended management activities to occur (Phillips et al. 2000). The principal cause of the degradation of water quality associated with harvesting activities is soil erosion from highly disturbed areas such as roads and log landings, with eventual sedimentation in streams (Kochenderfer et al. 1997). The process of erosion involves detachment, transport, and subsequent deposition of the soil particles (Meyer and Wischmeier 1969). Preventing sedimentation is a major goal for adequate application, effectiveness, and compliance of BMPs. As early as 1955 it was stated that without careful placement and installation of roads and landings, sedimentation will increase beyond normal geologic processes (Tebo 1955, Reinhart et al. 1963, Hewlett 1979). Installation of water bars aided in skid trail stabilization and provided short- and long-term erosion control (Patric 1977, Rothwell 1983).

BMPs are growing ever more important and are focused on preventing or reducing degradation of water quality from non-point source pollution, thereby decreasing erosion, protecting aquatic habitat, and maintaining aquatic communities (Carroll et al. 2004). Soil movement into water ways is the major concern when discussing the proper use of BMPs during timber harvesting. The West Virginia Legislature passed the Logging Sediment Control Act (LSCA) in 1992, which requires logging operations to incorporate the BMPs and to comply with additional regulations including logger licensing, logger certification, harvesting operation notification, reclamation, and enforcement capability for activities causing erosion and sedimentation on logging sites (Wang et al. 2004). The West Virginia Division of Forestry (WVDOF) is responsible for assessing timber harvests and also has the authority to issue citations for not complying with BMPs. Each timber harvest requires the overview of a certified logger and the WVDOF visits the site a minimum of three times during the harvest. These visitations generally occur within 3 days of beginning and end, and also at some midpoint during the harvest. With the compliance assessments in place and extensive workshop and outreach programs conducted by the WVDOF, it appears more emphasis has been paid to the BMP guidelines by foresters and timber harvesters based upon high levels of compliance in previous assessments. The numerous workshops and programs serve as a venue to address new methods of achieving BMPs and allow timber harvesters to learn more about the most current practices being applied. These venues also allow the WVDOF to address key points on which timber harvesters should focus. Silvicultural practices are currently exempt from nonpoint source pollution because BMPs are required. If compliance levels de-

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crease, then timber harvesting could be at risk from exemption from nonpoint source pollution contributors. The Environmental Protection Agency has also expressed the need for improved assessment of BMP effectiveness in order to maintain the "silvicultural exemption" (Ryder and Edwards 2006).

Assessing effectiveness of BMPs will determine how well they are working when constructed properly (Ellefson et al. 2001). Although BMPs have been studied extensively in different regions, most of the previous studies analyzed the compliance or effectiveness statistically. West Virginia has focused on compliance studies and needs to have a basis for further examination of application and effectiveness of BMPs. Using spatial features to analyze BMPs may also aid foresters in pre-harvest planning procedures. Therefore, the objective of this study was to examine how spatial factors can potentially influence BMP application, effectiveness, and compliance in West Virginia.

Methods and Materials

Data

Spatial features, compliance, application, and effectiveness were assessed on 33 sites in West Virginia. This sample is from a larger pool assessed for BMP compliance. The 33 sites were selected based on the following methods. Sites were randomly sampled in each of the six forest districts in West Virginia during the sampling time period from November 2003 to March 2004. Forest District 3 typically has the most logging activity in the state. Therefore, it was used for the basis of the study. A random sample size of 30 sites out of 347 sites was selected from Forest District 3. The number of sites to be sampled in the other districts was determined by multiplying the total harvested sites in that district during the sampling time period by the ratio of 30:347 (Wang et al. 2007a).

Once the number of samples was determined, the harvesting notification forms were obtained for the sites selected to be assessed. Sample sites were selected based on the same procedures used in the 1996 study to permit consistent comparisons (Egan et al. 1998, Wang et al. 2007b). A random sample generator was used to determine the specific sites. Landowner permission was obtained to visit each site for BMP assessment. A total of 116 sites were sampled for the statewide BMP compliance assessment, of which 33 sites with SMZs were assessed for BMP application, effectiveness, and compliance using the 12 checklists in this study. The 33 sampled sites were assessed for application and effectiveness when SMZs were found pertaining to the harvest. These sites were scattered across the different districts and were not sampled using any regularity in reference to district. The 33 sampled sites were essentially a random sample when a SMZ was found on site. The checklists used in this study were similar to those used in the 1996 survey performed by Egan and Rowe (1997), which covered haul roads, skid trails, landings, and SMZs. The checklists were used to assess presence and number of BMPs such as water bars, lengths seeded and mulched, grade, and other BMPs. The checklists were derived from the state BMP guidelines and updated during this assessment to incorporate changes and additions, specifically those found in the SMZ section (WVDOF 2005). Methods for determining compliance were based upon the state BMP guidelines.

Application and effectiveness assessed similar categories utilizing rankings in order to perform statistical analysis (Wang and Goff 2008). Application and effectiveness were assessed based on construction and durability over time. Compliance was assessed solely due to presence of a required BMP. For instance, there are a required number of water bars in a section of skid trail dependent upon grade and distance. If the required number is present – the trail is 100 percent compliant, but if not it could be 75 percent or even not compliant with regard to water bars. But, application was assessed based on criteria as to how well a presented BMP was applied. There are guidelines for applying BMPs provided by the state, but these are recommendations and there could be alternative practices that are acceptable.

A total of 29 BMPs were measured in the field (**Table 1**). Slopes of skid trails, haul roads, and SMZs were measured using a clinometer. Slope measurements of the roads were taken at either grade breaks or curves. This allowed each road segment to be analyzed separately. Water bar requirements vary depending on length and slope of each segment. The average slope of each tract was determined by using an elevation grid of the state provided by the United States Geological Survey (USGS and SAMB 2005), which allowed for comparisons of slopes among forest districts and harvest methods. Length measurements for each section of skid trail and haul road were taken with a laser rangefinder. Length measurements also included length of gravel, seeding, and mulching. Seeding and mulching requirements were assessed visually on the landings and sections of roads and trails. Length measurements were also taken for berm and smooth sections of road. A smooth section of road or trail is one that contains ruts less than 6 inches deep or none at all. Landings were also assessed for location, drainage, and smoothness.

Sites with SMZs generally require additional precautions during harvesting. Application and effectiveness checklists included similar data fields as the compliance checklists, but focused on their application and effectiveness over time. Specifically, the appearance of surface erosion or runoff was visually categorized by using these checklists. Rankings for application and effectiveness of BMPs used in this study were similar to those used in two previous studies (Ohio DOF 1999, Schuler and Briggs 2000). The three rankings for application of BMPs were:

0 for BMP not used or poor application,

1 for BMP attempted with minor deviations, and

2 for BMP used and correctly applied.

The five rankings for BMP effectiveness included:

0 for no effect,

1 for poor,

2 for fair,

3 for good, and

4 for excellent.

Table 1. ~ *BMPs and operational variables assessed in the field.*

Haul road	Skid trail	Landing	SMZ
Segment (#)[a]	Section (#)[a]	Landing (#)[a]	SMZ (#)
Length (m)[a]	Length (m)[a]	SMZ violation (y/n)	SMZ width (m)
Grade (#)	Grade (#)	Number of roads leaving landing (#)[a]	Equipment operations (y/n)
3.65 m (12 ft) minimum width[b]	Culverts or bridges used (y/n)[b]	Number of roads diverted (#)	Soil exposed (y/n)[a]
Stream crossed at right angle (y/n)[b]	Stream crossed at right angle (y/n)[b]	Landing smooth (y/n)[a]	SMZ stabilized (y/n)[a]
Culvert used (y/n)	No skidding in streams[b]	Landing drained (y/n)[a]	Landing outside of SMZ (y/n)
Culvert needed (y/n)	Waterbars (#)	Landing seeded (y/n)	Landing reclaimed(y/n)
Culverts clear of debris (y/n)[b]	Waterbars needed (#)	Landing mulched (y/n)	Haul road outside SMZ (y/n)
Gravel used (m)	Length smooth (m)[a]	Minimum size (y/n)[b]	Haul road reclaimed (y/n)
Gravel needed (m)	Length of berm (m)[a]		Existing roads (y/n)[a]
Length seeded (m)	Length outsloped (m)[a]		Existing roads used (y/n)[a]
Length needing seed (m)	Length seeded (m)		Riprap installed (y/n)[a]
Mulched (y/n)	Length needing seed (m)		Skid road outside SMZ (m)
Mulch needed (y/n)	Mulched (y/n)		Skid road reclaimed (m)
Avoid wet areas (y/n)[b]	Mulch needed (y/n)		SMZ slope (%)
SMZ violation (m)	SMZ violation (m)		
Stream length (m)[a]	Stream length (m)		
	Spacing of 61 m (200 ft)[b]		

[a] BMPs and operational variables were only assessed for compliance.
[b] BMPs and operational variables were only assessed for application and effectiveness.

Surface erosion was evaluated visually and based upon varying degrees of soil movement. The evaluation determined the effectiveness levels of the BMPs. Surface erosion was assessed based on soil movement into streams and areas where the soil disturbance was impacted due to the harvest, which could affect water flow due to BMP failure.

Spatial location data were collected for road and landing layouts, landing boundaries, haul roads and skid trails, water bar placement, and any SMZ widths and lengths, by using a GeoXT GPS unit. Spatial data included point, polygon, and line features. Data were transferred from the GPS to an office computer in which data were viewed and corrected using GPS Pathfinder Office 2.90. Once the GPS data were corrected, they were overlaid onto Digital Raster Graphic (DRG) maps of each site. Digital Orthophoto Quarter Quadrangles (DOQQs) were downloaded from the West Virginia GIS Technical Center (USGS and SAMB 2005) and were also used to map the data. Soil attributes for each site were derived from both Soil Survey Geographic Database (SSURGO) and State Soil Survey Database (STATSGO) in West Virginia. This data included erosion hazard, runoff potential, equipment limitation values, and moisture capacity information for each soil series encountered. Data from the 2000 census block group dataset was used to determine how the population may have affected BMP application, effectiveness, and compliance (WV Census 2002). Stream type was identified in the field or by using maps to determine perennial, intermittent, and ephemeral streams. A moisture index was analyzed using elevation, slope, and aspect grids (Wilson and Gallant 2000).

Analysis

The length measurements were used to determine the percent compliance of BMPs such as length smooth, berm removed, length outsloped, length graveled, and lengths that are within the acceptable grade. A ratio was obtained by dividing the number of water bars constructed in a segment by the number of water bars that are required by the BMP guidelines. A compliance level for each trail or segment was determined using this method. For some data fields measured on landings or in SMZs with a yes or no answer, either 1 or 0 was assigned to compute the compliance percentages. The ranking for application or effectiveness assigned to each BMP at each site was divided by the highest possible ranking (2 for application and 4 for effectiveness) to compute the application or effectiveness percent rate for that BMP. These BMP application and effectiveness percentages were then grouped by stream type, SMZ width, population density, soil series, and other factors for further analysis.

Spatial feature relationships among compliance, application, and effectiveness were examined for each site. Locations were analyzed using slope, soil attributes, flow accumulation, SMZ width, road and landing layout, stream type, and site moisture index. Road and landing layout characteristics such as aspect, landing location, and haul road and skid trail placement were analyzed using a moisture index and soil attributes. This allowed for further discussion of preplanning using factors found on an individual site for the entire harvest. Flow accumulation rasters were used to analyze stream crossings and examine if there were alternative locations for better stream crossings. This approach allowed the harvest to be examined based on known placement of haul roads, skid trails, and landings in relation to high overland flow drainage accumulation. The flow accumulation analysis allows the forest manager or logger to plan the harvest in such a way to avoid these areas as much as possible, thus limiting the opportunity for surface erosion and the need for extensive reclamation. The ability to track the path of surface flow using the raindrop tool option in the hydro modeling extension of ESRI ArcGIS was also used to determine the best option for road, trail, and landing placement in case of a storm event (ESRI 2004). The raindrop tool allowed analysis of areas on the harvest that may have required more reclamation or better planning. This tool predicts overland flow of precipitation using the path of least resistance based on elevation. Once precipitation reaches a road or trail, BMPs must be in place to direct flow. This tool is useful when examining preharvest plans to avoid areas that may receive a great deal of overland flow naturally.

Streams were digitized and buffers created to determine the area that was disturbed by equipment activity inside the actual SMZ. Knowing the actual buffers from the site allowed for observation of equipment activity including trail and landing construction inside the buffer. Stream crossings are expected, but need to be planned very carefully. It is not good practice to construct landings or trails in close proximity to or parallel to streams. Measuring the actual SMZ width allowed for analysis based on stream type and possible modifications for this SMZ. Once the GPS data were overlaid, a map was created to view the area on a larger scale. The straight-line distance method from ArcGIS was used to determine the distance from haul roads, skid trails, and landings from the stream and SMZ. The purpose of this approach was to illustrate the harvest infrastructure location in relationship to topography and proximity of the SMZ of each site (**Fig. 1**). A distance grid was calculated using the SMZ location, which is dependent upon stream type.

Each site was also assigned to a watershed and a stream that would receive any potential runoff. This information allowed for comparison of the harvested area to the watershed acreage. Flow direction and flow accumulation grids were also used for delineating and analyzing stream networks. Using this network, the data collected from the field were used to analyze interactions with smaller scale drainage basins. A drainage area of 2.2 hectares (5.5 acres) was used to view stream networks in relation to the harvest. Small-scale watersheds were examined to specifically concentrate on the main aspects of a harvest, such as landings, roads, and trails, which provide a better understanding of the spatial factors, which potentially could have affected the harvest such as elevation and topography, as well as the stream network of the watershed.

Road and landing layouts were specifically analyzed to determine whether better placement would have decreased the risk of erosion. The soil moisture indices of the sites were classified as dry, moist, and wet using the natural log of slope and accumulation grids. A simple moisture index based on surface water flow models was used (Parker 1982, O'Loughlin 1986, Moore et al. 1988, Grayson et al. 1992, Mitasova et al. 1996). This model assumes that the relative moisture in a particular area (in our case a grid cell) primarily depends on two factors: how much water is flowing into the area and how fast the water can flow out of the area. The catchment area is determined for each cell. This is the amount of upslope area (or the number of cells) that contributes water to the cell. The slope at the cell then

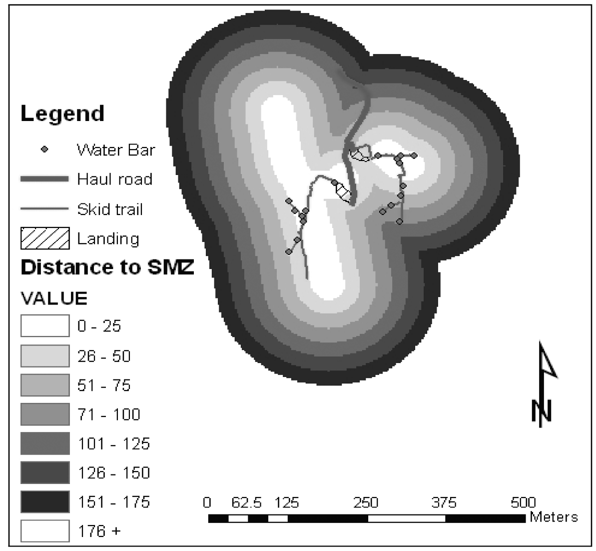

Figure 1. ~ *Distance raster with topography of a sampled site.*

determines how fast the water can run off the cell. The following ratio combines these two indices:

$$R = Ln\left\{\frac{ca+1}{slope+1}\right\} \qquad [\mathbf{1}]$$

where:

Ln = natural logarithm,

ca = catchment area (m^2), and

$slope$ = average slope of a grid cell (°).

R is a relative moisture index so the resulting numbers do not have units, yet the higher, more positive numbers are wetter and the lower, more negative,numbers are drier. Dry, moist, and wet classifications were derived using this method. The wet areas are near streams, which are generally found in coves in the Appalachian region. Coves are areas that fall between ridgelines and are often shaded and wet or moist. These areas typically show signs of ephemeral streams during wet periods. Moist areas are located in close proximity to streams and often remain moist after a precipitation event for a short time. The dry areas are likely ridge tops that tend to be drier in the region.

Soil attributes of each site were examined to evaluate roads and landing locations. The SMZ areas were also mapped with soil attributes to determine which attributes were most often affected in these areas. It could be used to evaluate whether a landing had poor drainage from the soil attributes or poor construction. The drainage description for soil series was derived from the soil survey (U.S. Soil Survey Division 2001). The topography, roads, landings, soils, and surrounding area were all employed to analyze the relationships among BMP application, effectiveness, compliance, road and landing layout, and other site factors.

Erosion hazards and equipment limitations associated with soils were also examined in the study. Classifications for these two fields were found using soil surveys for West Virginia (U.S. Soil Survey Division 2001). The erosion hazard of a soil was defined as the probability that damage will occur as a result of site preparation and soil disturbance where soil is exposed along roads and other disturbed areas. The ratings for erosion hazard are determined by slope. A rating of slight denotes there are no particular precautions needed. A moderate rating suggests that preventions are needed for certain silvicultural activities. A rating of severe indicates that special precautions are needed to control erosion in most silvicultural activities.

Equipment limitation reflects characteristics and conditions of soils that restrict use of equipment generally needed in harvesting and forest management (U.S. Soil Survey Division 2001). The main characteristics considered are slope, stones on surface, rock outcrops, soil wetness, and texture of surface layer. With a rating of slight, there are no significant restrictions on the kind of equipment and reason of use due to soil factors. Soil wetness can restrict equipment use, but only if the wet period exceeds 1 month. A moderate rating restricts equipment use because of one or more soil factors. If the soil is wet, wetness restricts equipment use for 1 to 3 months during the year. A rating of severe indicates that operations are severely restricted as to the kind of equipment that can be used or the type of use. If the soil is wet, equipment use is restricted for more than 3 months out of the year.

Five major soil series were noticed on these sites. The Berks soil series tend to have lower ratings for the two focused soil characteristics. This site had ratings of slight for both equipment limitations and erosion hazard. The Gilpin soil series had slightly higher ratings for the characteristics of erosion hazard and equipment limitation, which was found in some of the sites. The Dekalb and Dormont series are moderately deep and well-drained with slight to moderate ratings for both erosion hazard and equipment limitations. The Moshannon series presents ratings of slight to severe erosion hazards and equipment limitations.

The BMP application, effectiveness, and compliance were also compared statistically among stream type, SMZ width, soil series, population, and moisture index using a general linear model (GLM).

$$BMP_{ijklm} = \mu + ST_i + SMZ_j + SS_k + P_l + MI_m + ST_iSMZ_j + SMZ_jSS_k + SMZ_jMI_m + \varepsilon_{ijklmn}$$

$$i = 1,2,3$$
$$j = 1,2,3$$
$$k = 1,2,\ldots,5$$
$$l = 1,2,..,9$$
$$m = 1,2,3 \qquad [2]$$

where:

BMP_{ijklmn} = the n^{th} observation of the measured BMP application, effectiveness, or compliance,

μ = grand mean of each response variable,

ST_i = the effect of the i^{th} stream type,

SMZ_j = the effect of the j^{th} SMZ width,

SS_k = the effect of the k^{th} soil series,

P_l = the effect of the l^{th} population factor,

MI_m = the effect of the m^{th} soil moisture index, and

ε_{ijklmn} = an error component that represents uncontrolled variability.

The interactions among stream type, SMZ width, soil series, and moisture index were also considered in the model.

Results

Road and Landing Layout

The road and landing layout was analyzed for each site using flow accumulation grids created in ArcGIS. A good example of pre-harvest planning showed that the haul road, skid trails, and landing were constructed away from high flow accumulation areas with a reasonable size of landing (**Fig. 2a**) while a less than optimal example of infrastructure layout illustrated that the landing and skid trails were constructed in high flow accumula-

a)

b)

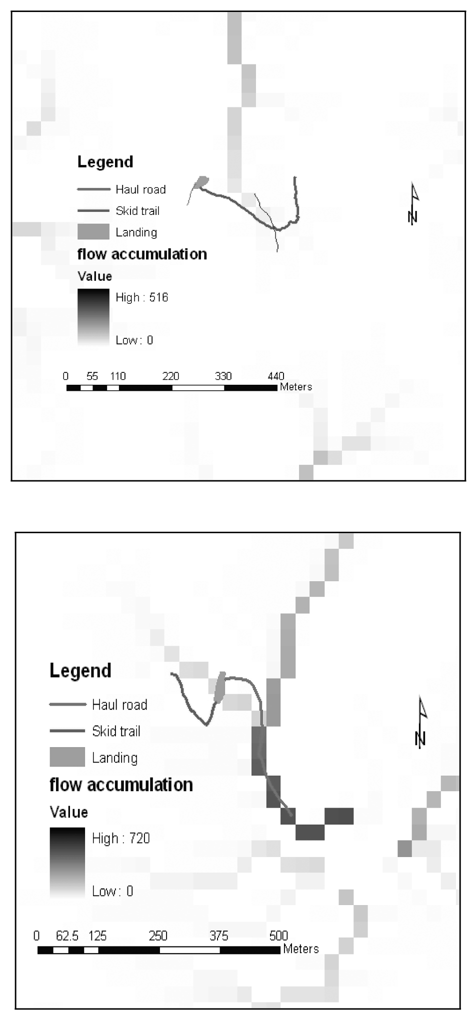

Figure 2. ~ *Flow accumulation analysis of two sampled sites.*

tion areas (**Fig. 2b**). This could possibly be avoided when using pre-harvest planning to determine location of roads and landings. The road and landing layout in **Figure 2b** could easily create BMP problems during wet periods and also during reclamation. Additionally, reclamation would be more extensive due to the poorly placed infrastructure. This is a costly practice and could easily be avoided. With the final placement of infrastructure, the harvest may have been delayed during a precipitation event when perhaps this could have been avoided if drier sites were chosen. Based upon the road and landing layout and proximity to streams, the sites which presented a great deal of infrastructure construction in high flow accumulation areas had lower percentages of average compliance (59%) and effectiveness (62%) than the harvests with activity concentrated far away from high flow accumulation areas (compliance 87% and effectiveness 84%). It was found that even well applied BMPs were not found to be as effective in the areas of high flow accumulation.

Stream Type

Of the 33 sites, 46 percent contained intermittent streams, 37 percent had ephemeral streams, and 17 percent had perennial streams. Perennial and intermittent streams require a 30.48 m (100 ft) buffer for the SMZ, while a 7.62 m (25 ft) buffer is needed for ephemeral streams (WVDOF 2005). Average landing size by stream type was between 0.04 hectares (0.1 acres) and 0.06 hectares (0.15 acres). Landings on sites with perennial streams averaged 16.15 m (53 ft) away from the streams, which did not meet 30.48 m (100 ft) buffer as required by the BMPs (**Table 2**). Landings on sites with perennial streams were located on higher elevation, but still many of them were constructed inside of, or near, SMZs. The major SMZ violations involved skid trails, which only averaged 3.05 m (10 ft) away from the perennial streams. When a stream crossing has to be made during a harvest, the proper precautions must be taken. It is beneficial to the timber harvester to keep this occurrence to a minimum because stream crossing and reclamation are costly. Ideally, skid trails should be outside of the SMZ except when crossing a stream. The haul roads were generally constructed away from the perennial streams. The erosion hazard was severe on 37 percent of the sites containing perennial streams.

BMP application ($p = 0.4343$) and effectiveness ($p = 0.6850$) rates on sites with intermittent and ephemeral streams were higher than on sites with perennial streams but they were not significantly different. Even though SMZ violations occurred in some sites, the BMPs were applied and were effective enough to reduce the risk of erosion on these sites. Lower application and effectiveness levels for water bars applied, trail spacing, and stream crossings at the proper angle on sites with perennial streams could be attributed to the construction of trails in close proximity to higher volumes of water expected with perennial streams (**Table 2**). Compliance was also found to be lower on

Table 2. ~ *Means and ranges of BMPs and operational variables by stream type.*

	Stream type					
	Perennial		Intermittent		Ephemeral	
	Mean	Range	Mean	Range	Mean	Range
Operational variables						
Landing size (ha)	0.04	0.016 to 0.057	0.06	0.04 to 0.089	0.06	0.04 to 0.081
Landing elevation (m)	170	75 to 258	121	64 to 221	99	70 to 214
Landing slope (%)	20	7 to 49	13	5 to 23	19	7 to 39
Landing distance from SMZ (m)	16	0 to 49	21	0 to 33	54	0 to 61
Skid trail slope (%)	9	5 to 13	9	5 to 12	8	5 to 12
Skid trail distance from SMZ (m)	3	0 to 9	2	0 to 10	10	0 to 9
Haul road slope (%)	5	2.5 to 10	6	1 to 17	7	2 to 17
Haul road distance from SMZ (m)	41	0 to 49	31	0 to 37	72	0 to 55
SMZ slope (%)	5	0 to 15	6	1 to 11	3	2 to 7
Erosion hazard[a] (%)						
Slight	38	--	--	--	50	--
Moderate	25	--	88	--	50	--
Severe	37	--	12	--	--	--
Equipment limitation[a] (%)						
Slight	40	--	--	--	66	--
Moderate	40	--	57	--	34	--
Severe	20	--	43	--	--	--
BMP performance[b] (%)						
Application	83a	66.5 to 92.7	90a	76.7 to 100	90a	63.3 to 100
Effectiveness	79a	62.8 to 95	87a	70.3 to 100	90a	82.5 to 96.3
Compliance	60a	45 to 78	72a	45 to 99	69a	47 to 83

[a] Values represent the average percentage of sites containing this rating.
[b] Means with the letter of a row are not significantly different at the 5-percent level with Duncan's Multiple-Range Test.

these sites with an average of 60 percent, and it did not differ significantly from compliance rates on sites with intermittent and ephemeral streams ($p = 0.9851$) (**Table 2**).

SMZ Width

The BMP application, effectiveness, and compliance rates generally increased with the SMZ width (**Table 3**). Some sites, however, proved that rates were acceptable with a narrow SMZ width, which means proper BMP construction by the timber harvester. The application rate for sites with 0 to 7.62 m (0 to 25 ft) of SMZ width was 85 percent, which was the lowest among the three SMZ widths, as was the effectiveness level of 80 percent. But, both application ($p = 0.7313$) and effectiveness ($p = 0.8136$) rates were not significantly different among SMZ widths. These application and effectiveness levels could have a direct impact on runoff and sedimentation with these close proximities to the streams. A relatively lower average BMP compliance of 65 percent was found for these sites. There was no significant difference in compliance among SMZ widths ($p = 0.6541$).

The BMP compliance on sites that had the landings constructed between 7.93 m (26 ft) and 30.48 m (100 ft) away from streams was 68 percent while the application and effectiveness levels were 90 percent and 83 percent, respectively, on these sites. These sites contained 50 percent each of moderate and severe rankings for both erosion hazard and equipment limitations. Sites with SMZ widths greater than 30.48 m (100 ft) had an overall compliance of 73 percent due to the wider SMZs and higher BMP application and effectiveness rates. Erosion hazards and equipment limitations had slightly decreased ratings on these sites.

Soil Series

The Dekalb soil series is made up of stony material and is generally well-drained (U.S. Soil Survey Division 2001). The low moisture rating found in this soil could have possibly aided the effectiveness of the BMPs applied (86%). The BMP compliance found for this soil series averaged 60 percent (**Table 4**). The Gilpin soils have similar characteristics to the Dekalb series and are also well-drained and moderately deep. The average BMP application and effectiveness rates on the sites with primarily Gilpin soils were 83 percent, with a slightly higher BMP compliance of 66 percent. Berks soils are well-drained, but they erode readily. The low compliance of 60 percent and effectiveness rate of 78 percent could be explained by the erosion factor of this soil series. This erosion factor has the potential to degrade improperly installed BMPs and, therefore, reduce their effectiveness over time. Moshannon soils are present near streams and in flood plains. Sites of this soil series presented average application and effectiveness levels of 82 percent. There was no significant difference in BMP application ($p = 0.3588$), effectiveness ($p = 0.8712$), and compliance ($p = 0.8212$) among soil series.

Population

The data gathered indicated that application, effectiveness, and compliance of BMPs generally increased with population density across the state (**Table 5**). This possibly could be due to fewer sites sampled in the populated areas or that less attention

Table 3. ~ *Means and ranges of BMPs and operational variables by SMZ width.*

	SMZ width (m)					
	0 to 7.62		8 to 30.48		30.48+	
	Mean	Range	Mean	Range	Mean	Range
Operational variables						
Landing size (ha)	0.04	0.016 to 0.089	0.04	0.04 to 0.057	0.04	0.02 to 0.081
Landing elevation (m)	186	70 to 258	147	88 to 214	109	64 to 174
Landing slope (%)	18	6 to 49	12	5 to 27	12	5 to 16
Skid trail slope (%)	9	4.7 to 12.7	7	4.6 to 11.9	--	5 to 8
Haul road slope (%)	7	2 to 17	5	2 to 11.5	4	0 to 5
SMZ slope (%)	5	0 to 11	6	3.5 to 7	5	4 to 7
Erosion hazard[a] (%)						
Slight	33	--	--	--	33	--
Moderate	40	--	50	--	33	--
Severe	27	--	50	--	33	--
Equipment limitation[a] (%)						
Slight	33	--	--	--	33	--
Moderate	40	--	50	--	33	--
Severe	27	--	50	--	33	--
BMP performance[b] (%)						
Application	85a	66.5 to 100	90a	63.3 to 100	90a	78.3 to 94.3
Effectiveness	80a	62.8 to 97.3	83a	75.3 to 100	88a	85.8 to 88.7
Compliance	65a	45 to 99	68a	45 to 94	73a	51 to 75

[a] Values represent the average percentage of sites containing this rating.
[b] Means with the letter of a row are not significantly different at the 5-percent level with Duncan's Multiple-Range Test.

Table 4. ~ *Means and ranges of BMPs and operational variables by soil series.*

	Soil series									
	Gilpin		Berks		Delkab		Moshannon		Dormont	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Operational variables										
Landing size (ha)	0.04	0.016 to 0.089	0.04	0.02 to 0.081	0.04	0.04 to 0.053	0.081	0.053 to 0.081	0.045	0.045
Landing elevation (m)	156	64 to 221	118	70 to 220	187	124 to 258	76	67 to 84	108	108
Landing slope (%)	16	5 to 49	14	7 to 22	21	7 to 39	16	10 to 26	15	15
Landing distance from SMZ (m)	34	0 to 49	33	0 to 61	16	0 to 29	0	0	0	0
Skid trail slope (%)	9	4.9 to 12	9	5 to 12.7	7	4.6 to 10.6	11	9.5 to 12	9.6	9.6
Skid trail distance from SMZ (m)	4	0 to 9	0	0	5	0 to 9	0	0	0	0
Haul road slope (%)	6	1 to 17	6	2.3 to 17	5	2 to 10	4	4	3	3
Haul road distance from SMZ (m)	41	0 to 49	35	0 to 55	88	9 to 46	0	0	9	9
SMZ slope (%)	6	0 to 10	5	2 to 8	4	2 to 6	5	1 to 15	11	11
Erosion hazard[a] (%)										
Slight	--	--	50	--	100	--	33	--	--	--
Moderate	82	--	50	--	--	--	33	--	100	--
Severe	18	--	--	--	--	--	33	--	--	--
Equipment limitation[a] (%)										
Slight	50	--	50	--	100	--	100	--	--	--
Moderate	50	--	25	--	--	--	--	--	100	--
Severe	--	--	25	--	--	--	--	--	--	--
BMP performance[b] (%)										
Application	83a	78.3 to 100	86a	63.3 to 92.8	86a	69.8 to 96.3	82a	79.3 to 98.7	87a	87
Effectiveness	83a	70.3 to 100	78a	62.8 to 97.3	86a	82.5 to 96.3	82a	71 to 97.3	81a	81
Compliance	66a	50 to 99	60a	45 to 72	60a	47 to 77	69a	55 to 78	70a	70

[a] Values represent the average percentage of sites containing this rating.
[b] Means with the letter of a row are not significantly different at the 5-percent level with Duncan's Multiple-Range Test.

Table 5. ~ *BMP application, effectiveness, and compliance means and ranges by population density.*[a]

People per 2.59 km^2 (square mile)	Application		Effectiveness		Compliance	
	Mean	Range	Mean	Range	Mean	Range
	(%)					
< 10,000	81a	63.3 to 93	79a	62.8 to 83	60ab	45 to 100
10,001 to 15,000	90a	78 to 93	85a	64 to 95	50b	45 to 73
15,001 to 20,000	87a	67 to 91	72a	63 to 86	72ab	65 to 100
20,001 to 25,000	85a	67 to 100	79a	65 to 86	70ab	54 to 88
25,001 to 30,000	100a	100	94a	86 to 99.3	73ab	54 to 79
40,001 to 50,000	100a	100	86a	100	71ab	63 to 100
70,000 to 80,000	92a	87 to 98.7	85a	85 to 94	77ab	72 to 100
80,001 to 200,000	90a	--	92a	--	82a	73 to 97
> 200,001	90a	--	84a	--	80a	78 to 98

[a] Means with the letter of a column are not significantly different at the 5-percent level with Duncan's Multiple-Range Test.

was paid to the BMP application and effectiveness in less populated areas. The possibility of higher levels of application, effectiveness, and compliance could be attributed to aesthetic values noted by the timber harvester who was required to clean up after a timber harvest and reclaim roads, skid trails, and landings. But, there was no significant difference in application (p = 0.4888), effectiveness (p = 0.8144), and compliance (p = 0.8353) among population categories. With the increased potential for the public to see the site, the timber harvester's motivation may be increased to properly conduct the BMPs or even go beyond the minimum requirements. The lower levels of application and effectiveness may also be due to a lack of public visitation to the site, or possible problems encountered due to topography or other site factors.

Moisture Index

BMP application, effectiveness, and compliance were analyzed using moisture indices of the sites and viewed as a predictor in relation to road and landing layout. The moisture index output display is used for planning so different stream types can

Table 6. ~ *Means and ranges of BMP application, effectiveness, and compliance by moisture index.*[a]

Moisture index	Application		Effectiveness		Compliance	
	Mean	Range	Mean	Range	Mean	Range
	(%)					
Dry	95a	78 to 100	89a	73 to 100	78a	63 to 100
Moist	88a	65 to 100	86a	68 to 100	70a	54 to 100
Wet	84a	63.3 to 100	77a	62.8 to 94	64a	45 to 94

[a] Means with the letter of a column are not significantly different at the 5-percent level with Duncan's Multiple-Range Test.

be taken into account with required infrastructure. The average application levels changed from 84 to 95 percent, while the effectiveness levels varied from 77 to 89 percent when the site moisture level changed from wet to dry (**Table 6**). BMP application and effectiveness levels were higher on dry sites with 95 percent and 89 percent, respectively. Accordingly, dry sites presented a higher average compliance level of 78 percent compared to 70 percent and 64 percent for moist and wet sites, respectively. Application ($p = 0.3029$), effectiveness ($p = 0.7712$), and compliance ($p = 0.2129$) of BMPs, however, did not differ significantly among moisture indices.

Discussion

Analyzing spatial features is popular for natural resource applications in agricultural systems and forest ecosystems at different scales to reduce erosion and nutrient loss (Berry et al. 2003, Berry et al. 2005). In forest ecosystems, tracking the overland flow of precipitation would enable foresters to gain insight in road and landing placement in pre-harvest planning. There is obviously a greater amount of water flow in coves or hollows, and this amount increases closer to perennial streams. Flow accumulation grids can be efficiently used to layout forest roads and landings. If used in pre-harvest planning, it could save time and reclamation costs in the field.

Precautions need to be observed and BMPs required while harvesting timber especially near sensitive waterways or areas. Huang et al. (1996) showed that direct impacts of timber harvesting can either increase or decrease soil hydraulic properties, depending on soil texture, structure, and soil moisture during harvesting. Our results suggest that foresters and timber harvesters can benefit from spatial data and pre-harvest planning to take proper precautions when operating in sensitive areas. For example, water bars and cross drainages can be constructed to redirect overland flow from a road or skid trail. Areas showing high flow accumulation can be avoided if the planning is done properly before going to the field.

BMP application, effectiveness, and compliance should be examined on a regular basis for the state of West Virginia, which would allow the WVDOF to continue to address BMP related problems and revise the BMP guidelines accordingly. Understanding site factors using the analysis of spatial features would benefit many foresters and timber harvesters during road and landing layout as well as at the closing of the harvest. The assessment process along with the workshops for timber harvesters could improve the application of BMPs, which could ultimately increase their effectiveness levels in the state. Compliance is monitored by the WVDOF, but could easily be addressed during regular assessments across the state. Implementing the methods and results from this assessment in the training classes could allow the WVDOF to better educate the foresters and timber harvesters on BMPs and harvest planning in West Virginia. A great deal of time, effort, and money can be put into completing a timber harvest if proper precautions are ignored. Stressing the importance of pre-harvest planning to timber harvesters and foresters has the potential to save both time and money during the closing of the harvest. Foresters have the potential to utilize methods described in this study to guide timber harvesters through the pre-harvest planning stage and finally to the close out of the harvest. By analyzing the potential harvest site using spatial features, roads, trails, and landings can be planned prior to going to the site. Importing features from a GIS system into a GPS will allow precise placement of the infrastructure throughout the harvest. Any on-site problems can be alleviated by finding alternative locations.

It was found that sites located with a higher population generally included fewer streams and resulted in better BMP application, effectiveness, and compliance in West Virginia. This could be due to smaller tracts being harvested, as well as fewer problems encountered in these areas. Harvested sites sampled in less populated areas are generally located in secluded areas that are more mountainous and exhibit more stream networks. These factors highlight the importance of analyzing spatial features of a secluded site during pre-harvest planning. High population density sites can also create some problems for timber harvesters when working on smaller tracts of land. The forest operations may be restricted to where infrastructure can be placed due to ownership boundaries. These are additional constraints that merit the need for pre-harvest planning.

Conclusions

Compliance associated with streams and SMZ width showed that sites with perennial streams received a lower compliance ranking as did the sites with the narrower SMZ widths. Compliance increased with SMZ width as did both application and effectiveness. The results, however, show a poor trend concerning stream type. The values for application and effectiveness of BMPs appear to be decreasing from ephemeral to perennial streams. Also as expected, relatively lower rankings were found on wet and moist sites compared to dry sites using the moisture index analysis. This necessitates the need for more precaution and better planning when harvesting close to major streams.

Lower levels of BMP application and effectiveness were presented on sites which had equipment operations closer to streams. This could be resolved by focusing efforts during pre-harvest planning and conveying to the timber harvester the importance of applying BMPs in these sensitive areas. This work could be done prior to harvesting or in the field after analyzing spatial features to determine where problem areas may arise.

We observed a variation in BMP compliance associated with the USDA Natural Resource Conservation Service soil interpretation ratings for erosion hazard and equipment limitation. High risk of erosion sites were often moist sites. This is a constant conflict when harvesting near a stream and the reason why it is necessary to properly install BMPs and ensure their effectiveness over time. Sites with the least sensitive soils presented higher compliance levels. These results conclude that the BMPs were applied correctly and were effective in such areas. Sites containing more sensitive soils usually presented lower levels of BMP compliance. But, reasonable levels of compliance were found on sites with more sensitive soils, which reflected that the BMPs were applied and also effective on these sites. The effectiveness of the BMPs applied was better understood based on the interactions of slope, soil, and flow accumulation. The BMPs need to be well applied to be effective on sensitive soils and where flow accumulation can be high. It is best to avoid high flow accumulation areas and place roads and landings at higher elevations when possible. When these factors were found to be detrimental to harvesting activities, the BMPs had to be applied correctly and effectively to prevent runoff. A low compliance was often the result when the BMPs were not applied or were not effective. This suggests that in order for application and effectiveness levels to be high, BMP compliance also needs to be met which underlies the need for compliance with the current BMPs in West Virginia.

The application and effectiveness of BMPs is becoming increasingly more important. Recent literature has shown a trend to assess application and effectiveness of BMPs rather than their overall compliance. Assessing these aspects of the BMPs across the state would allow for comparisons among other states in the region (Ryder and Edwards 2005) and should be the focus in future assessments of BMPs in West Virginia. Compliance of BMPs should still play a major role in assessment, but application and effectiveness assessments are necessary to determine practices that are being applied on timber harvests across the state. Assessing the quality and compliance of BMPs using spatial features provides harvesting managers and foresters with a useful tool for pre-harvest planning and the landowners with a visual aid of the planned harvest activities. Pre-harvest planning will allow all parties involved to gain a complete understanding of the timber harvesting process, and with the combined use of spatial features, mapping, and field knowledge, the harvest can prove to be efficient and less costly at closure.

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