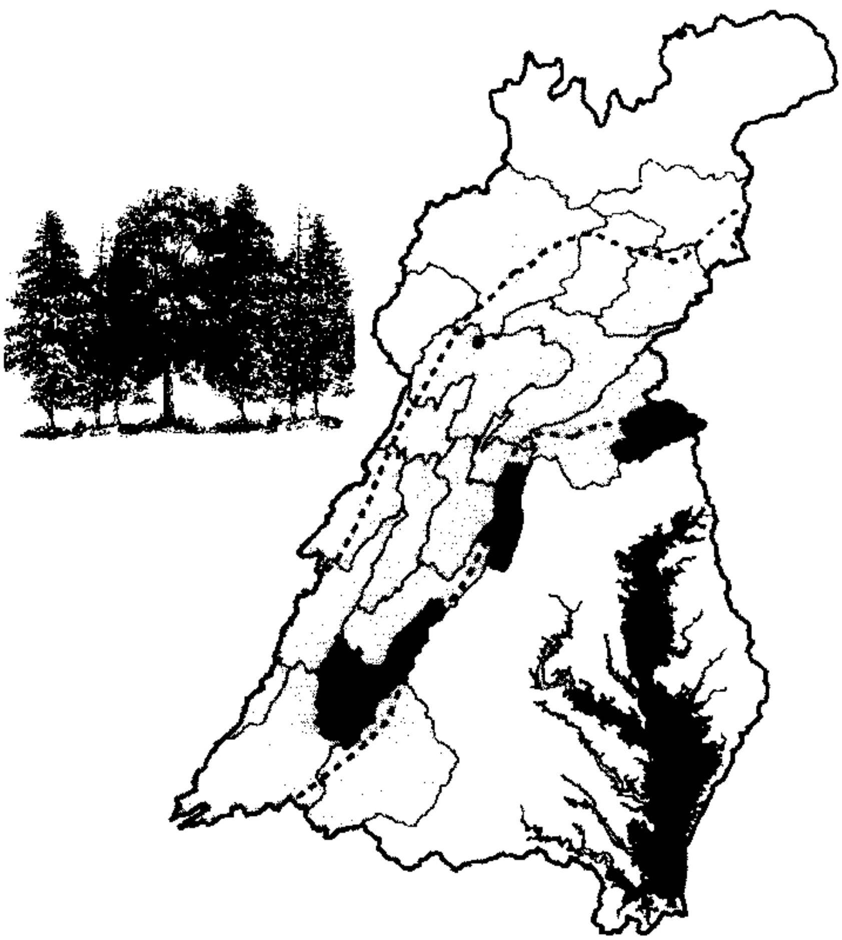
CHESAPEAKE BAY PROGRAM

Nutrient Subcommittee

Forestry Best Management Practices and Water Quality in the Piedmont and Ridge-And-Valley Provinces of the Chesapeake Bay Watershed



NSC Publication 97-1

About the Nutrient Subcommittee

The Nutrient Subcommittee (NSC) is concerned with identifying and controlling of nutrient discharges to the Chesapeake Bay from point and nonpoint sources. The primary charge to the Subcommittee is to improve nutrient pollution programs and implementation of nutrient reduction strategies among the jurisdictions and agencies through technology transfers.

The Subcommittee is responsible for (1) cooperative design, coordination, and assessment of point and nonpoint pollution control programs and practices; (2) Tributary Strategy coordination, progress tracking and issue resolution; (3) 1997 Reevaluation of the Tributary Strategies; (4) annual report of progress toward the CBP Year 2000 nutrient reduction goals; and (5) identification and support of needed nutrient-related research.

The Subcommittee develops control-program criteria, establishes methods of collecting and evaluating results of nutrient programs and practices, identifies and coordinates needed research and promotes sharing information, education and training.

NSC studies and publications are supported by the U.S. Environmental Protection Agency (EPA) through cooperative agreement CB-993043-04 with the Chesapeake Research Consortium, Inc..

Acknowledgments

Reviewers

John Barber	Forestry Workgroup, Chair
Albert Todd	USFS/ Chesapeake Bay Program Office

Layout and Cover Design

Usha Govindarajulu	Chesapeake Research Consortium, Inc.

To receive additional copies of this publication, contact the Chesapeake Bay Program (1-800-968-7229; 410-267-5700) and request the publication by title or contact their website: http://www.epa.gov/r3chespk

Chesapeake Research Consortium, Inc.
645 Contees Wharf Road
Edgewater, Maryland 21037-0028
Telephone: 301-261-4500; 410-798-1283
Fax: 410-798-0816
Electronic mail: crc@chesapeake.org
http://www.chesapeake.org/crc/crc.html

CHESAPEAKE BAY PROGRAM
Nutrient Subcommittee

Forestry Best Management Practices and Water Quality in the Piedmont and Ridge-And-Valley Provinces of the Chesapeake Bay Watershed

Steven Seagle and D. Daniel Boone
Appalachian Laboratory
University of Maryland Center for Environmental Science

NSC Publication 97-1

July 1997

Printed on Recycled Paper

TABLE OF CONTENTS

ABSTRACT

A literature review was conducted to determine the effectiveness of forestry best management practices (BMPs) in reducing water quality impacts of forestry management operations within the Piedmont and Ridge-and-Valley of the Chesapeake Bay watershed (CBW). Two aspects of BMP effectiveness were addressed: the ability of BMPs to reduce impacts on water quality, and compliance with state-recommended BMPs.

A comparison of the published forestry BMPs for each of the states within the Bay watershed indicated considerable variation among the states in specific BMPs recommended. In general, definitions and provisions for protection of intermittent streams, ephemeral streams, and wetlands not in streamside management zones appear in need of clarification and probably strengthening. Within the CBW, only Virginia and Maryland currently have published BMP compliance reports. Although very different in methods, these reports identified similar diffuse problems, such as skid trail locations, and point problems, such as stream crossings, as critical areas for improvement. Further long-term BMP compliance monitoring by all of the Bay states is recommended.

The literature for both sediment and nutrient reduction by forestry BMPs qualitatively support the fact that BMPs are effective when properly implemented. Direct measures of the percent reduction in sediment or nutrients by one or more BMPs is difficult to find because most relevant studies were not formulated to test BMPs, and thus appropriate controls to separate harvest from BMP effects are lacking. Only one published study that experimentally addresses forestry BMP effects on sediment and nutrient loss from the harvest site has been carried out in the CBW Piedmont or Ridge-and-Valley. However, this study appears to be highly representative of the Ridge and Valley province. Ongoing research and demonstration studies in different ecoregions would be a valuable asset to forestry BMP programs throughout the CBW.

Future studies aimed at determining BMP effectiveness should be designed to provide specific estimates of the percent reduction in sediment and nutrient that can be attributed to the BMPs. This information could be an important parameter in discussions of (1) whether BMPs should be regulatory or voluntary, (2) what levels of nutrient flux from forest management activities are controllable versus uncontrollable, (3) cost-benefit analyses of BMP programs and enforcement, and (4) how to assign "fair share" reductions in nutrient loads to meet environmental or policy goals for surface or ground water quality. Future work is also needed for implementation of forestry BMPs in a landscape context that considers cumulative watershed effects of the BMP in controlling both on-site and off-site environmental impacts.

INTRODUCTION

Ecological functions of forests include provision of a clean and continuous water supply, soil stabilization and sediment retention, nutrient and carbon storage, production of wood products, moderation of woodland stream temperatures, provision of energy input for streams, and maintenance of wildlife and fisheries habitat (Spurr and Barnes 1980). All of these functions are interrelated to determine local environmental quality. Nutrient and sediment retention by forests are also of primary importance in landscape and regional environmental quality because of the ability of forests to act as filters of nutrient runoff from other land uses, thereby reducing cumulative effects within large watersheds that feed coastal and estuarine ecosystems such as the Chesapeake Bay. The central role that forests play in regional environmental quality dictates a regional perspective on forest ecosystem function and management.

Temporal And Spatial Variation Of Forests And Their Functions

Since European settlement the pattern and tempo of forest dynamics in the Chesapeake Bay watershed (CBW) have been largely a function of human activity. Cooksey and Todd (1996) documented the history of CBW forests, from near complete forest cover before European settlement, to a low of 30-40% cover around 1900, and reforestation to about 62% forest cover by 1970. Impacts from this historical deforestation in the CBW have been documented, with deforestation from 1650-1850 AD correlated with increased sedimentation, water turbidity, water column eutrophication, and bottom water anoxia in the Chesapeake Bay (Cooper 1995). Recent forest trends include a net loss of 4-5% forest cover within the CBW (A.H. Todd, personal communication). This loss has not been a simple decline but a regional mosaic of gains in New York and West Virginia, no change in Pennsylvania, and losses in Maryland and Virginia (Cooksey and Todd 1996). Even within Maryland and Virginia these losses are spatially variable and concentrated in the urban/suburban eastern parts of the states (Dobson and Bright 1995). The overall impact of humans on forest distribution has been fragmentation. In terms of ecological services rendered, the value of remaining forest fragments must rise. For example, because forests are more retentive of nutrients and sediments than most other land uses within the CBW (Fisher and Oppenheimer 1991), their value for preserving regional water quality by filtering nutrient and sediments from other land uses must increase as total forest amount declines. Thus while changes in total forest area within the CBW are important, the distribution and wise management of remaining forests and their ecological function is paramount.

Forests of the CBW represent a variety of forest types and concomitant variation in forest function. For the eastern United States, Hornbeck et al. (1987) suggested that northern hardwood forests tend to retain sediments, but leak nutrients such as nitrogen. Furthermore, more southern sites dominated by oaks (Quercus spp.) and other mesic species show the opposite trend of retaining nutrients and losing sediment. Such a trend in nitrogen loss is difficult to document for forests of the CBW. Hunsaker et al. (1995) reviewed nitrogen export from forested catchments of the CBW and found ranges of 0.04 - 2.4 and 0.07 - 0.18 kg/ha/yr for nitrate and ammonium, respectively. We discerned no evident spatial patterns in these export values. DeWalle and Pionke (1995) also examined rates of nitrogen export from small forested watersheds distributed across the CBW and suggested that forests in the north and southeast portion of the CBW have notably higher rates of nitrogen export. Gardner et al. (1996) found a similar pattern and documented export rates of 0.05 - 5.15 and 0.16 - 2.12 kg/ha/yr for nitrate and ammonium, respectively. Both DeWalle and Pionke (1995) and Gardner et al. (1996) noted that spatial patterns of higher export rates within the CBW reflect areas of higher and lower atmospheric nitrogen deposition. Significant variation even within those portions of the CBW where export rates are higher suggests that local factors such as forest composition, forest disturbance, land use history, soil structure, topography, or hydrogeology may also play important roles in nitrogen export. Based on these studies we conclude that the mechanisms controlling nitrogen loss from forests without recent disturbance in the CBW are not well understood.

Forest Nutrient Retention, Disturbance, And Best Management Practices

Multiple mechanisms, including low soil ammonium levels, nitrification inhibition, reduction of nitrate to ammonium, nitrate adsorption, denitrification, and water conservation, all contribute to the ability of forests to retain nitrogen (Vitousek and Melillo 1979, Melillo 1981). Conversely, it is clear that forest disturbances, such as harvesting (Likens et al. 1970; Marks and Bormann 1972; Johnson et al. 1982; Swank 1986, 1988; Lynch and Corbett 1990), site preparation after harvesting (Richter et al. 1982; Vitousek and Matson 1984, 1985; Binkley et al. 1992), and defoliation (Swank et al. 1981, Webb et al. 1995), can at least temporarily decrease the ability of forests to retain nutrients and sediment.

The influences of forest harvesting, site preparation, and forest regeneration activities on water quality have been reviewed multiple times (Stone et al. 1978, Yoho 1980, Martin et al. 1984, Ursic 1986, Riekerk et al. 1989, Binkley and Brown 1993a,b). Most recently, Binkley and Brown (1993a,b) comprehensively reviewed regional effects of forest management on water quality within the United States. Their review focused largely on data from U.S. Department of Agriculture (USDA) Forest Service experimental forests and U.S. Geological Service benchmark watersheds, and supplemented that information with data from other agency or state research sites. Collectively, Binkley and Brown's (1993b) studies from the eastern United States extended over a broader geographical range than the CBW, but certainly included many of the physiographic provinces found in the CBW. Although the sample sizes for comparison were small and the data was presented in a very condensed manner, Binkley and Brown (1993b) found a notable impact of most management practices on streamwater nitrogen and sediment concentrations, considerable variation in impact among forest management practices, and a high variation of impacts within the eastern United States (Table 1). Binkley and Brown (1993a) summarized their data from specific studies at 14 sites for the southeast and 7 sites for the northeast United States. Of these 21 sites only one is within the CBW. For the southeast, they stated that "harvesting generally has no substantial effect on stream water chemistry but that intensive site preparation has the potential to greatly increase sediment loads, especially in steep terrain" (Binkley and Brown 1993a). For the northeast United States, Binkley and Brown (1993a) found less focus on sedimentation and greater focus on nitrogen because relatively high nitrogen fluxes are associated with harvesting of northern hardwood forests (Binkley and Brown 1993b). Although northern hardwood forests generally do have greater nitrogen effluxes after harvesting, both Martin et al. (1984) and Binkley and Brown (1993b) concluded that those watersheds with greatest stream water nitrogen concentrations after harvesting (the Hubbard Brook watersheds in New Hampshire) are atypical, and that harvesting does not degrade water quality in terms of nitrogen concentrations. Data for the entire eastern United States clearly indicated that sedimentation is highly variable by site, management practices (especially related to logging roads, skid trails, and log landings), and degree of site preparation after harvest (Binkley and Brown 1993a,b). These factors make suspended sediment the major water quality concern for forest harvesting (Binkley and Brown 1993b). Both a limited

Table 1. Overview of the effects of forest management practices on streamwater nitrate nitrogen and suspended sediment in the eastern United States. All information is derived from tabulations by Binkley and Brown (1993b).

STATE	MANAGEMENT	CONTROL	TREATMENT	REFERENCE
Nitrate nitrogen concentration (mg/l)[1]				
FL	80% clearcut	0.03	0.04	Riekerk (1983)
GA	100% clearcut	0.14	0.05	Hewlett et al. (1984)
SC	Prescribe burn	0.10	0.10	Richter et al. (1982)
SC	Water drainage	0.50	0.90	Askew and Williams (1986)
NC	Clearcut	0.018	1.30	Swank (1988)
NH	100% clearcut	0.20	3.90	Hornbeck et al. (1987)
PA	44% clearcut	0.03	0.08	Lynch et al. (1985)
WV	100% clearcut	0.20	0.20	Aubertin and Patric (1974)
Suspended sediment concentration (mg/l)				
FL	80% clearcut	3.0	4.0-13.0[2]	Riekerk (1983)
SC	100% clearcut, burn	19.0	72.0[3]	Van Lear et al (1985)
TN	100% clearcut	82	183[4]	McClurkin et al. (1985)
MS	100% clearcut, chop	2127	2471[5]	Beasley (1979)
MS	100% clearcut, shear	2127	2837[5]	Beasley (1979)
PA	43% harvest	1.7	5.9[6]	Lynch et al. (1975)
PA	Clearcut, herbicide	1.7	80[7]	Lynch et al. (1975)

1 Nitrate concentrations are indexed by the maximum annual average concentration in post-treatment years of record.
2 Two-year average. The values represent minimum and maximum harvest impact.
3 Maximum annual average in three years.
4 Maximum during stormflow in three years.
5 Maximum annual average in two years.
6 Three-year average.
7 Two-year average.

amount of eastern data and nation-wide information suggested that phosphorus releases after harvesting do not degrade water quality (Salminen and Beschta 1991, Binkley and Brown 1993b).

We generally concur with these assessments, especially concerning sediment, but suggest that forestry impacts on nitrogen be considered in a different context. First, most studies reviewed by Brown and Binkley (1993a,b) displayed an increase in stream nitrogen levels following forest harvesting. These increases were occasionally substantial and often variable in longevity. In isolation, these elevated nitrogen fluxes are quite probably benign, but their effects are seldom assessed as cumulative impacts (Reid 1993). Secondly, Binkley and Brown (1993a,b) judged the severity of stream nitrogen increases by federal drinking water standards (10 mg nitrate nitrogen/l). Obviously this is an important standard because managed forest watersheds are important sources of drinking water. This standard is also well-defined legally, but not ecologically. Thus, in the context of non-point source pollution control for the CBW, it is (1) unclear whether a drinking water standard is appropriate for gauging impacts, and (2) incumbent to consider cumulative eutrophication effects from multiple forest management projects distributed throughout the watershed. In addition, if indeed forests of the eastern United States are becoming nitrogen saturated (Aber et al. 1989) through atmospheric deposition, then many forests of the CBW may be heavily impacted because those portions of the CBW that are most heavily forested receive some of the highest nitrogen deposition rates in the eastern United States (Gardner et al. 1996). Whether some forests within the CBW are nitrogen saturated (Aber et al. 1989, DeWalle and Pionke 1995) and could produce large pulses of streamwater nitrogen if harvested remains unclear (Binkley and Brown 1993a, Gardner et al. 1996). Collectively, these questions make a strong case for further understanding how, where, and to what extent forest management influences forest nitrogen release.

For managed disturbances, like forest harvesting, multiple techniques have been developed to alleviate nutrient and sediment loss. These best management practices (BMPs) are defined as "those methods, measures, or practices to prevent or reduce water pollution and include but are not limited to structural and nonstructural controls, and operation and maintenance procedures. BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters" (40 C.F.R.35.1521-(4)(c)(1), 1984). The identification, description, and implementation of non-point pollution controls by individual states are mandated by Section 319 of the federal Water Quality Act of 1987. Specific BMP effectiveness, and thus validity, may vary among states and throughout the CBW because of natural physical or biological conditions and compliance with BMP guidelines. Thus for large watersheds like the CBW, which cross the boundaries of multiple states, it is important to assess the types, effectiveness, and compliance rates for recommended BMPs.

Forestry Best Management Practices And Public Policy

The U.S. Environmental Protection Agency's Chesapeake Bay watershed model (Linker et al. 1994) is the primary tool currently used to assess nutrient and sediment loading to the Chesapeake Bay, and the geographic and land use sources of those loadings (Donigian et al. 1994). These assessments have been used in formulation of multi-state nutrient management policy, particularly the Chesapeake Bay Agreement whose goal is to strategically reduce controllable nitrogen and phosphorus loads to the Chesapeake Bay by 40% by the year 2000. Controllable nutrients are defined as "the difference between the 1985 base load and the load from a totally forested (undisturbed) watershed" (Chesapeake Bay Program 1994). An interesting application of the Bay model has been to assess potential reductions in nutrients and sediment entering Chesapeake Bay if all proven and recommended technologies to abate non-point and point sources were implemented (Linker 1994, Shulyer 1995). This simulation represented a "limit of technology" scenario designed to identify potential future reductions and the cost effectiveness of different categories of BMPs (Shulyer 1995). For this simulation, forestry BMPs were implemented as a percent reduction in loadings by state: PA - 5%, MD - 7.5%, and VA - 10% for each of ammonium, phosphate, and BOD (biochemical oxygen demand), respectively (Shulyer 1995). Because neither specific data on effectiveness of BMPs nor the methodology to scale such data to the entire CBW were available, these reduction percentages were estimated largely by professional opinion. While this methodology is not optimal, it is reasonable when the sensitivity of results to the percent reduction is considered and a range of potential outcomes is presented. Nonetheless, more specific data on forestry BMP effectiveness for controlling non-point source pollution will be important to future BMP cost-benefit analyses. In addition, implementation plans, or tributary strategies (Chesapeake Bay Program 1994), to achieve nutrient reduction goals vary among the Bay agreement signatory states, with each state charged to define technical strategies to meet the reductions allocated to it. Forest management BMPs will play a major role for some of these tributaries. To truly predict the impact of BMP implementation and facilitate local planning, more exact information on the effectiveness of BMPs and compliance with BMPs will be needed.

OBJECTIVES

Our general objective in undertaking this review was to compile information on forestry BMPs used within the CBW and analyze the scientific basis for those BMPs. To meet this objective, we have specified four tasks:

1. To compile and contrast forestry BMPs for those states having forest land area within the CBW, and summarize compliance with the BMPs recommended by each state.

2. To review published studies of BMP effectiveness for reducing nitrogen, phosphorus, and sediment pollution within the central Atlantic region, with particular emphasis on studies within the CBW.

3. To consider the breadth of applicability for BMP studies within the CBW by examining the geographical and biological range reflected by the sites under which the studies were carried out.

4. To suggest research or monitoring objectives for enhancement of forestry BMP implementation and effectiveness in protecting water quality.

METHODS

Comparison of Best Management Practices

We obtained the most recent documentation of best management practices recommended for timber management operations from the government agency administering this effort in each of the six states of the Chesapeake Bay Watershed. To assess similarities and differences among the states' recommendations for protecting water quality during timber harvest operations, BMP procedures and practices for each state were summarized in three ways. First, a simple listing of BMPs was derived by reviewing all six state BMP publications and scoring which states either explicitly or implicitly recommend each BMP. Second, a brief summary of each state's recommended BMPs was derived to provide enough detail that readers can compare them based on general aspects such as stream definitions, buffer width slope corrections, etc. Finally, the summaries for each state were further abstracted to provide direct tabular comparisons among the states. While we have attempted to retain accuracy, no doubt detail was lost in each of these summaries. Thus we caution readers that a truly complete understanding and full representation of the BMPs for each state are best derived from the original state manuals. Because of vagaries in definitions and the wide range among the states in number of BMPs recommended, no attempt was made to quantitatively analyze differences in BMPs among the Bay states.

Literature Search

Literature pertinent to the role of forestry best management practices in maintaining water quality was identified by (1) compiling published papers or reports from our personal libraries, (2) soliciting suggested references from forestry or watershed professionals employed by state agencies or universities within each state of the CBW, (3) scrutiny of library holdings and/or bibliographies of publications from U.S. Forest Service experimental forests, and (4) computerized literature searches of library holdings. Multiple key references were already maintained in our personal research files. However, these files had not been developed in a systematic manner to cover the entire Chesapeake Bay region. By soliciting information from forestry professionals within state agencies and universities, we attempted to expand our reference coverage spatially to the entire CBW. Responses from this mail and telephone effort were only moderately successful. Nonetheless, references obtained by these two methods provided a baseline of important studies on which to gauge the success and effectiveness of our computerized literature searches.

Our computerized searches utilized several databases: DISSERTATION ABSTRACTS, BIOSIS, AGRICOLA, CAB ABSTRACTS, and BIOLOGICAL AND AGRICULTURAL INDEX. Queries to these databases used keywords and concept phrases (e.g. best management practice, forestry, forest harvesting, water quality, and logging) crafted to identify publications of interest. Successive iterations allowed development of reference lists for different geographic extents and specificity of topic. For example, specifying the geographic extent as "Piedmont and Ridge and Valley of eastern North America", and the key words as "forestry" and "best management practice", led to a very limited number of highly pertinent references, but excluded influential related works outside these physiographic provinces. In addition, database structures differed and necessitated adaptation of search techniques. As an example, most databases do not have a geographic delimiter. Thus multiple queries and adaptations for each database were required in order to identify the optimal combination of key words and key concepts to focus the search on the most relevant citations. BIOSIS and AGRICOLA were the most productive databases. Combined use of all databases resulted in a master list of approximately 1,000 references that either addressed our topic generally or were specific studies within the geographic area of interest. We estimated the effectiveness of our computer search by selecting 20 references, ranging in focus from best management practices in general to specific research studies in the Chesapeake Bay region, from our personal files or those recommended by regional professionals as a "test" data set. Of these references, 13 (65%) were also identified by the computerized searches.

As expected, computerized searches were least efficient in identifying state and federal documents dealing with best management practices. Thus, to supplement the searches, we reviewed bibliographies of published works from three U.S. Forest Service (USFS) facilities: Coweeta Hydrologic Laboratory (NC), Fernow Experimental Forest (WV), and Hubbard Brook Experimental Forest (NH). Although none of these facilities is within the CBW, each has a rich history of forestry research that includes seminal work on best management practices. Pertinent publications from these bibliographies were added to the reference list generated by computer searches. As individual publications were reviewed, particularly promising citations in them were also noted for acquisition and subsequent review.

This master list of references, derived from computer searches, input from regional professionals, and USFS bibliographies, was scrutinized and a sublist of what we felt were the most important references was developed for use in this review. Copies of papers and documents were obtained by photocopying in libraries (Beltsville Agricultural Research Center library, University of Maryland - College Park library, Pennsylvania State University library, and Frostburg State University library), interlibrary loan, or requests from public agencies. In addition, we examined the holdings of the USFS Coweeta Hydrologic Laboratory library in person. References that we obtained were reviewed and those still considered pertinent to this review were entered into a bibliographic database (ProCite 3.1; Personal Bibliographic Software 1994). Our literature search process also identified an unpublished computerized database containing over 2,000 citations focused exclusively on water quality and forest management (Dissmeyer 1993). This database was obtained from the USFS in a ProCite 3.1 format and searched for important references not already included in our database.

Literature Evaluation

References in our database were keyworded to provide information about the scope and nature of the publication. The geographic location, type of study, physiographic province, vegetation type, water quality parameters, and type of BMP tested/used were included as keywords to describe those references dealing with controlled experimental or observational studies. Keywords were used to identify those studies that provided (1) general information about forestry and best management practices that could be important to the region, or (2) information specific to the CBW. In general, we limited this review to studies carried out in the eastern United States and to those physiographic provinces that are part of the CBW. These subsets of the database were further broken down by (1) state, (2) physiographic province, (3) specific BMP(s) being examined, (4) characteristics of the study (e.g. paired watershed, experimental, long-term monitoring, replicated design, etc.), and (5) resulting impacts on water quality. After reviewing the results of this categorization, the number of studies within categories was judged inadequate for statistical analysis. Thus we resorted to a critical review of subset of studies that addressed either sediment or nutrient water quality impacts of BMPs used during forest management activities.

Geographic Applicability of Experimental Results

The CBW is diverse in geology, topography, forest types, hydrology, and climate. All of these physical and biological factors influence forest ecosystem ecology and the success of best management practices. Therefore, it is important to consider methodologies to evaluate where within the CBW any particular study of BMP effectiveness might be applicable. To accomplish this, we used the PC ARC/INFO Version 3.4.2 (ESRI 1992) geographic information system (GIS) to develop a spatial database for the CBW that included the CBW boundary, major subbasin boundaries, state and county boundaries, ecoregions, hydrologic segments from the U.S. Environmental Protection Agency's Chesapeake Bay watershed model (HSP-F; Linker et al. 1994), and forest types as point data from the most recent USFS Forest Inventory and Analysis (Alerich 1990; Alerich and Drake 1995; DiGiovanni 1990; Frieswyk and DiGiovanni 1988a,b; Hansen et al. 1992; Johnson 1992).

This spatial database uses the Universal Trans Mercator (UTM) projection system, with meters as the unit of distance. To construct the database, digital maps of the CBW boundary, subbasin, and hydrologic segments were obtained from the U.S. Environmental Protection Agency's Chesapeake Bay Program. Computerized boundaries for ecoregions of the United States were obtained from the U.S. Forest Service (Bailey 1994), converted to a UTM - meters coordinate system, and boundaries within the CBW clipped from the national data set. Likewise, the digital boundaries for each of the six states contributing to the CBW were converted to UTM - meters and joined to the other layers of the GIS. Forest Inventory and Analysis (FIA) data, from the USFS, represents field plot studies that estimate forest resources of the United States. To obtain forest types and their distribution, the USFS uses satellite imagery (AVHRR) to record presence of forest within km^2 pixels. To estimate forest types and distributions throughout the CBW, we used the plot data summary from the FIA Eastwide Data Base (Hansen et al. 1992) for each of the six Bay states. Plot level information for the mid-Atlantic region was converted into an ARC/INFO point coverage in which all attribute information was linked to the spatial location ("point") of the plot, as defined by the latitude/longitude coordinates. A GIS layer which delineated the spatial boundary of the CBW was then used to clip the point coverage, thus selecting only those FIA plots within the CBW. An estimate of the forest acreage, type, topography (ie., slope and aspect), and moisture class (e.g. mesic, xeric, etc.) was then made for the entire CBW and/or ecoregions based on plot data. The FIA field measurements associated with each plot are also part of the database and provide a rich resource to describe forest and site characteristics over large areas. By specifying site data (latitude, longitude, forest type, slope, aspect, etc.) from forestry BMP studies it is a relatively straightforward GIS exercise to estimate the amount and location of similar CBW forest land. The GIS was also used to estimate the types and amount of forest type within the Chesapeake Bay watershed by state, ecoregion, ownership, slope class, and aspect.

RESULTS AND DISCUSSION

The Piedmont and Ridge-And-Valley Provinces

Collectively, the Piedmont and Ridge-and-Valley (R&V) physiographic provinces comprise 55% of the Chesapeake Bay watershed (NCRI Chesapeake 1982), with 4,617,400 ha (32%) of land in the RAV and 3,262,900 ha (23%) in the Piedmont. Dominant landuses within these two provinces include forest and agriculture. The CBW RAV is approximately 58% forested, with an additional 31% in various types of cropland (excluding pasture). In comparison, the CBW Piedmont is 49% forested and 25% in cropland (NCRI Chesapeake 1982). For each province the remaining land area is used primarily for pasture and urban/suburban development. The prevalence of forest and its utilization for timber and pulpwood emphasize the importance for application of best management practices (BMPs) within each province.

Effectiveness of BMPs can be heavily influenced by hydrogeology. Folding and thrust faults, and the spatial distribution of sedimentary, metamorphic, and igneous rock types, create a complex geology for the Piedmont (Schmidt 1993). This geology underlies a topography of hills and stream valleys (Schmidt 1993). Because of its long geological history, weathering, and lack of glaciation, soils of the Piedmont are often quite deep on flat upland hilltops, but are commonly thin in stream valleys (Lowrance et al. 1993, Schmidt 1993). The long parallel ridges and valleys of the RAV, formed by weathering of limestone valleys between ridges of erosion-resistant sandstone, is also unglaciated and underlain largely by fractured sedimentary rock (Schmidt 1993). Typically, soils of the RAV are thinner than the Piedmont (Lowrance et al. 1993, Schmidt 1993). Because of spatial variation in bedrock of each province, patterns of water discharge can vary significantly within both the Piedmont and RAV. These patterns of soil depth and bedrock structure influence routes by which dissolved nutrients drain from watersheds and the potential effectiveness of BMPs for protection of stream water quality (Lowrance et al. 1993).

Forestry BMPs For States Of The Chesapeake Bay Watershed

By reviewing the BMP publications for all states in the CBW, a list of BMPs that have been recommended for use within the CBW was derived (Table 2). Wide variation in BMP description, emphasis, and details for implementation existed among the publications reviewed. Given the variation in forest types, soils, and climate found within and among the Bay states, this variation is not surprising and makes judgmental comparisons among states based on this list unfounded. Forest harvesting BMPs (Table 2) largely designate techniques for construction and maintenance of access and water control structures. An exception is establishment of streamside management zones (SMZs), which is a preserved rather than constructed BMP. Wetland BMPs are very similar to forest harvesting BMPs, but construction specifications consider hydric soils more explicitly. Site preparation BMPs detail the recommended use for various methods of site management to enhance the success of replanting. Within the CBW, site preparation BMPs carry most relevance for Coastal Plain and Piedmont forests, especially pine forests that are regularly planted rather than relying on natural regeneration. Revegetation BMPs aim to stabilize roads, log landings, skid trails, stream crossings, etc. by groundcover establishment. Forest protection BMPs control fire and insect damage to remaining trees, often with emphasis on SMZs.

BMP Comparison Among States

Based on BMP documentation supplied on request by each state government within the Chesapeake Bay watershed, we summarized the forestry BMPs for each state (Appendices A-F). These compendia are not meant to convey all specifics for each state; as such, they do not suffice for practical application in lieu of the original manuals. They do, however, provide a flavor of the variation in detail among the states for the general categories of BMP requirement status; government notification of logging operations; professional assistance in the logging operation; logger certification requirement; several aspects of streamside management zones (definition,

TABLE 2. Best management practices that are found in the written recommendations for each of the states in the Chesapeake Bay watershed. The state BMP manuals were highly variable in the definition, description, and amount of detail given for each BMP.

BEST MANAGEMENT PRACTICES	STATE					
	VA	WV	DE	MD	PA	NY
FOREST HARVESTING						
Haul Roads	X	X	X	X	X	X
Skid Trails	X	X	X	X	X	X
Log Decks & Landings	X	X	X	X	X	X
SMZ	X	X	X	X	X	X
Broad-Based Dips	X	X	X	X	X	X
Rolling Dips	X		X	X		X
Water Bars	X	X	X	X	X	X
Cross Road Drainage/Box Culverts	X	X	X	X	X	X
Stream Crossings (e.g. Culverts)	X	X	X	X	?	X
Water Turnouts/Diversion Ditches	X		X	X	X	X
Sediment Barriers					X	X
SITE PREPARATION						
Prescribe Burning	X		X	X		
Drum Chopping	X		X	X		
Disking	X		X	X		
Bulldozing/Shearing/Piling/Raking	X		X	X		
Bedding	X		X	X		
Machine Planting	X		X	X		
Pesticides	X		X	X		X
Forest Fertilization	X		X	X		
REVEGETATION						
Site and Seed Bed Preparation	X	X	X	X		X
Lime and Fertilizer	X	X	X	X	X	X
Seeding	X	X	X	X	X	X
Mulching	X	X	X	X	X	X
Maintenance	X		X	X	X	

(Continued)

TABLE 2. (Continued)

BEST MANAGEMENT PRACTICES	VA	WV	DE	MD	PA	NY
FOREST PROTECTION						
Wildfire Control and Reclamation	X		X	X		
SMZ Salvage and Sanitation	X	X	X	X	X	
WETLANDS						
Truck Haul Roads	X		X	X	X	
Skid Trails	X		X	X	X	
Log Decks	X		X	X	X	
SMZ	X		X	X	X	
Cross Drainages/Culverts	X		X	X		

minimum size, slope correction for size, restrictions for operating); wetland restrictions; soil stabilization; stream crossing requirements; log landings, roads and skid trails; soil erodibility considerations; and chemical use limitations. We feel that these categories represent the "basics" of the states' BMPs. In order to facilitate more direct comparison of forestry BMPs among the Chesapeake Bay states, we have further abstracted each state's BMPs into comparative tables (Tables 3 - 6). In condensing this information to tabular form we have tried to make the information accurate and accessible while simultaneously drawing contrasts among the states.

Maryland is the solitary Bay state that has regulatory power over the implementation of its forestry BMPs (Table 3). This regulatory power exists because the Maryland Department of the Environment (MDE) requires that any disturbance over 5,000 square feet have a sediment control plan, including BMPs. Forest operations are not exempt from this requirement and can be shut down if not complying with MDE-required BMPs.. Other states, notably Virginia and Pennsylvania, can close forest operations after a water quality problem is demonstrated. This is a clear difference in stringency of BMP requirements and thus we consider states other than Maryland to be voluntary in BMP compliance (Table 3). Further, Maryland and West Virginia are the only states that requires government notification when beginning a logging operation (Table 3). In accordance with these distinctions, both Maryland and West Virginia require the assistance of certified personnel in planning BMP implementation on logging sites (Table 3). Specifically, Maryland requires that a licensed forester provide planning for disturbance within the legally-defined streamside management zone (SMZ) and that at least one member of the logging team be trained in erosion and sediment control. West Virginia requires that a state certified logger supervise the operation at least once per day. West Virginia's logger certification program focuses on both safety and BMP implementation; Maryland has a similar "Master Logger" certification program. The Bay states uniformly specify the need for vegetative soil stabilization, although Pennsylvania does not specify the timing of stabilization relative to season or logging activities. Surprisingly, most Bay states do not consider soil erodibility, as determined

Table 3. Comparison of state-recommended best management practice guidelines for forest harvesting within the Chesapeake Bay watershed.

CHARACTERISTIC	STATE					
	VA	WV	DE	MD	PA	NY
BMP Implementation	Voluntary	Voluntary	Voluntary	Regulatory	Voluntary	Voluntary
State Government Agency Notification Required	No	Yes	No	Yes	No	No
Professional Assistance with BMP Implementation Required	No	Yes	No	Yes	No	No
Vegetative Soil Stabilization						
Timing	Specified	Specified	Specified	Specified	Not Specified	Specified
Location	Specified	Specified	Specified	Specified	Specified	Specified
Stream Crossings						
Permits	None	None	None	Required	Required	Required
Guidelines for stream type[1]	P, I, E	P, I, E	P, I	P, I	P, I[2]	P
Construction guidelines	Provided	Provided	Provided	Provided	Provided	Provided
Landing Engineering Specifications	Provided; Require 250' from SMZ	Provided	Provided	Provided	Provided	Provided; Rec. 200' from aquatic habitats

(Continued)

Table 3. (Continued)

CHARACTERISTIC	VA	WV	DE	MD	PA	NY
Roads/Skid Trail Engineering and Regulations[3]	Extensive	Moderate	Extensive	Extensive	Limited	Extensive
Soil Erodibility Consideration[4]	For roads on erodible soil	None	Seed. slopes; Traffic on erodible soil	None	None	None
Chemical Use Limitations[5]						
Pesticides	None	None	Not in SMZ	None	None	None
Fertilizers	Not near open water	None	Not in SMZ	None	None	None
Logger Training/Certification Required	No	Yes	No	Yes	No	No
Streamside Management Zone[6] Required	Yes	Yes	Yes	Yes	Yes	Yes

1 P = Perennial; I = Intermittent; E = Ephemeral streams.
2 Intermittent streams require permits to cross if they have a "defined bed and banks", and "normally flow in the wetter parts of the year (i.e., Oct - Apr) or after a major storm". Thus ephemeral streams may be included under this definition.
3 These broad categories represent our subjective judgment of the degree to which each state goes beyond engineering specifications in specifying efforts to protect water quality.
4 Aspect of highly erodible soils, as determined by soil surveys, are taken into account for best management practices.
5 Federal, state, and local laws take precedent and, in fact, are the recommended BMP for some states.
6 See Table 4 for more detailed comparisons of streamside management zone best management practices.

Table 4. Buffered watercourses, buffer widths for perennial, intermittent, and ephemeral streams, and disturbances allowed in the buffer zone as defined by state-recommended BMPs in the Chesapeake Bay watershed.

	STATE					
	VA	WV	DE	MD	PA	NY
BUFFERED WATERCOURSES						
Perennial Streams	---	yes	---	---	yes	yes
Blue-line[1] Only	yes		yes	yes		
Intermittent Streams	---	yes	---	---	no	no
Dashed Blue-line[2] Only	yes		yes	yes		
Ephemeral Streams	yes	yes	no	no	no	no
Open Water (ponds & lakes)	yes	undefined	yes	yes	no	yes
Nontidal Wetlands						
All Forested	yes	no	yes	no	no	no
Spring Seeps				no	yes	
Vernal Ponds				no	yes	
All Nonforested Wetlands	no	no	no	no	no	no
Marshes and bogs				yes	yes	yes
Blue-line wetlands Only[3]				yes		

1 "Blue-line" refers to presence of perennial watercourse or wetland feature on USGS 7.5-minute quadrangle maps.
2 "Dashed blue-line" refers to intermittent watercourses on USGS 7.5-minute quadrangle maps.
3 "Blue-line" wetland features are colored swamp and marsh symbols shown on USGS 7.5-minute quadrangle maps.

(Continued)

Table 4. (Continued)

	VA	WV	DE	MD	PA	NY
SMALLEST/LARGEST MINIMUM BUFFER (FT) FOR PERENNIAL STREAMS OR OPEN WATER BY DISTURBANCE TYPE						
Equipment Operation	0	0	0	50	0	50/100
Haul Roads[4]	50/125[5]	100/---	50/100	50/250	25/165[6]	100/150
Skid Trails[4]	50/125[5]	100/--	50/100	50/250	0	50/150
Landings	100/175[5]	100/-- (Where practical)	100/150	50/250 (100/300 recomm.)	25/165[6]	200
Humus Disturbance	50/125[5]	0	25	50/250	0	10
Timber Removal						
Selective Cutting	0	0	25/100	0	0	10
Clearcutting	50/125[5]	0	50/100	50/250	50	50

4 Generally excluding roads and skid trails permitted to cross streams.
5 Expand SMZ only for waters supporting trout; SMZ width for nearly all other streams remains the smallest minimum regardless of slope condition.
6 Widths <50 ft require a water obstruction permit or written waiver from state agency.

(Continued)

Table 4. (Continued)

	VA	WV	DE	MD	PA	NY
SMALLEST/LARGEST MINIMUM BUFFER (FT) FOR INTERMITTENT STREAMS BY DISTURBANCE TYPE						
Equipment Operation	0	0	0	50	0	0/--[7]
Haul Roads[4]	25/100[5]	100/--	50/100	50/250	0	0/--[7]
Skid Trails[4]	25/100[5]	100/--	50/100	50/250	0	0/--[7]
Landings	75/150[5]	100 (Where practical)	100/150	50/250 (100/300 recomm.)	0	0/--[7]
Humus Disturbance	25/100[5]	0	25	50/250	0	0/--[7]
Timber Removal						
Selective Cutting	0	0	0	0	0	0
Clearcutting	25/100[5]	0	50/100	50/250	0	0

4 Generally excluding roads and skid trails permitted to cross streams; stream crossing permits are required in some states.
5 Expand only for waters supporting trout; SMZ width for nearly all other streams remains the smallest minimum regardless of slope condition.
7 If an intermittent stream has flowing water (presumably at the time of harvesting), then it should be buffered just as a perennial stream; New York also recommends that intermittent stream channels not be used for skidding operations.

(Continued)

Table 4. (Continued)

SMALLEST/LARGEST MINIMUM BUFFER (FT) FOR EPHEMERAL STREAMS BY DISTURBANCE TYPE	VA	WV	DE	MD	PA	NY
Equipment Operation	0	0	0	0	0	0/--[9]
Haul Roads[4]	0	25	0	0	0[8]	0/--[9]
Skid Trails[4]	0	25	0	0	0[8]	0/--[9]
Landings	0	25 (Where practical)	0	0	0	0/--[9]
Humus Disturbance	0	0	0	0	0	0/--[9]
Timber Removal						
Selective Cutting	0	0	0	0	0	0
Clearcutting	25/100[5]	0	0	0	0	0

4 Generally excluding roads and skid trails permitted to cross streams; Stream crossing permits are required in some states.
5 Expand only for waters supporting trout; SMZ width for nearly all other streams remains the smallest minimum regardless of slope condition.
8 Pennsylvania affords special protection only for "spring seeps".
9 New York extends the same protection to flowing streams, whether perennial or intermittent; it is unclear whether ephemeral streams are governed by the same rules.

(Continued)

Table 4. (Continued)

POTENTIAL DISTURBANCES WITHIN STREAMSIDE MANAGEMENT ZONES	VA	WV	DE	MD[15]	PA	NY
	ACCEPTABILITY OF DISTURBANCES BASED ON STATE BMPs					
Equipment Operation	yes	yes	yes	yes[10]	yes	yes
Haul Roads[4]	no	no	no	no	yes[11]	no
Skid Roads[4]	no	no	yes	no	yes	--[12]
Landings	no	no	no	no	yes[11]	no
Soil Disturbance	no	yes	no	yes[10]	yes	yes
Timber Removal	yes	yes	yes	yes	yes	yes[13]
Partial Cutting	yes	yes	yes	yes	yes	yes[13]
Clearcutting	no	yes	yes[14]	no	yes[16]	yes[13]

4 Generally excluding roads and skid trails permitted to cross streams; Stream crossing permits are required in some states.
10 No equipment operation within 50 ft.
11 Not within 25 ft. Of perennial stream.
12 No skid roads within 50 ft. of a perennial stream if located on a slope >=10%.
13 No-cut zone of 10 ft. in width adjoining perennial streams or open water; Also a no-cut zone recommended for clearcuts adjacent to perennial streams
14 Requires a 25 ft. "no harvest zone" around perennial streams.
15 Any proposed disturbances within the SMZ require a buffer plan designed by a licensed professional forester.
16 No clearcutting is allowed within 50 ft of a perennial stream.

Table 5. Perennial and intermittent stream buffer zone width adjustments for slope as recommended BMPs for the states of the Chesapeake Bay watershed.

	STATE					
AVERAGE SLOPE TO WATERCOURSE	VA[1]	WV[2]	DE	MD	PA[4]	NY[4]
0 %		100		50	25[5]	100
1 - 10 %		100		75	45[5]	100
11 - 20 %		100		100	65	150
21 - 30 %		100		150	85	150
31 - 40 %		100		200	105	150
41 - 50 %		100		250	125	150
51 - 60 %		100		250	145	150
61 - 70 %		100		250	165	150
0 - 10 %	66		50[3]			
11 - 20 %	75		75[3]			
21 - 45 %	100		100			
>45 %	125		100			

1 Pertains to Virginia trout waters only - non-trout containing waters should be buffered 50 ft regardless of slope.
2 West Virginia requires a 25 ft filterstrip for ephemeral streams regardless of slope condition.
3 This number expands to 100 ft for "highly erodible soils" (based on soil series type).
4 These buffer adjustments apply only to perennial streams.
5 Width less than 50 ft require a permit or written waiver from state agency.

Table 6. An evaluation of the acceptability of potential disturbances for wetlands either within or outside of streamside management zones as recommended by the forestry best management practices of each state in the Chesapeake Bay watershed.

	DETERMINATION OF DISTURBANCE ACCEPTABILITY					
DISTURBANCE	VA	WV	DE	MD+	PA	NY
<u>WETLANDS WITHIN SMZ</u>						
Equipment Operation	yes	yes	yes	yes - 2	3	yes
Roads*	4	4	4,5	4,5	3,4	4,6
Skid Trails**	no - 1,2	no - 2	no - 1,2	no - 1,2	3	6
Landings	no	7	no	no	no	no
Soil Disturbance	no	yes	no	yes - 2	yes	yes
Timber Removal						
Partial Cutting	yes	yes	yes	yes	yes	yes
Clearcutting	no	yes	yes	no	yes	yes

(Continued)

Table 6. (Continued)

	VA	WV	DE	MD+	PA	NY
WETLANDS OUTSIDE OF SMZ						
Equipment Operation	yes	yes	yes	yes	7	yes
Roads*	4,8	4	4,8	4,5	4,7	4
Skid Trails**	yes	yes	yes	yes	7	yes
Landings	yes, if beyond 50' of SMZ	yes	7	9	7	yes
Timber Removal	yes - 10	yes - 10	yes - 10	yes - 10	yes - 10	yes -10
Soil Disturbance	yes	yes	yes	yes	yes	yes

* Roads are defined as a wetland fill, requiring federal permits; temporary roads (not bulldozed or graveled) may be exempt.
** Skid trails are defined here as roads or trails constructed without placement of fill.
+ In Maryland, any disturbances within the SMZ require the preparation of a buffer plan by a licensed professional forester.
1 An exception is for roads and skid trails legitimately needed to cross streams.
2 Not allowed within 50 ft of perennial or intermittent stream or open water.
3 Avoid unless no practical option exists. Additional protections afforded "spring seeps" and "vernal pond" wetlands. Temporary road crossing, if unavoidable, should cross wetland at narrowest place and be <200 ft length.
4 A federal and/or state wetlands disturbance permit is required.
5 Allowed no closer than 250 ft of perennial/intermittent stream or open water, except when needed to cross stream.
6 Not allowed within 100/150 ft of perennial stream or ponds/lakes, unless legitimately needed to cross wetland for logging operation.
7 Avoid unless no other practical option exists.
8 Truck haul roads not allowed within 200 ft of edge of SMZ - applies to wetlands adjoining open water or streams, exceptions for roads or skid trials legitimately needed to cross stream or wetland to complete logging operation.
9 Locate landings beyond 50 ft of SMZ on elevated lands or higher elevations as islands within wetlands.
10 Partial cutting or clearcutting is allowed by all states.

by soil surveys, in BMP implementation (Table 3). Delaware, in requiring special attention to seeding and traffic restriction, and Virginia, by limiting road grades, are exceptional in attention given to erodible soil. In addition to federal (Environmental Protection Agency) regulations on pesticide use near waterways, Delaware's BMPs have restrictions on pesticide and fertilizer use in SMZs and Virginia's forestry BMPs recommend against fertilizer use near open water. (Table 3).

All of the Bay states require SMZs or buffers along watercourses (Table 3). However, the definition of stream types, designation of SMZs, and description of SMZ activities vary significantly among the Bay states' BMP recommendations. Perennial streams are considered watercourses in need of buffers for all states. These streams are generally defined as having continuously flowing water year-round (or at least most years) by West Virginia, Pennsylvania, and New York. On the other hand, Maryland, Virginia, and Delaware define perennial streams as "blue line" streams on a U.S. Geological Survey 7.5 minute quad maps (Table 4). These definitions probably suffice for perennial streams. However, definitions of intermittent and ephemeral streams are more problematic. West Virginia and Pennsylvania provide concise definitions of an intermittent stream based on well-defined banks and a channel with water flowing only part of the year (Appendices D and F). Virginia, Delaware, and Maryland define these streams as "dashed blue lines" on 7.5 minute quad maps (Table 4). Moreover, New York relies on presence of flowing water to define whether a stream should be buffered. This definition presumably means that ephemeral streams should be buffered when logging and stream flow coincide, but buffering is not required if there is no streamflow. New York also recommends that dry streambeds not be used for skidding. This recommendation should perhaps be strengthened because there is evidence that unprotected intermittent and ephemeral streams can be significant sources of sediment (Lynch and Corbett 1990). Ephemeral streams require buffering only in Virginia and West Virginia (Table 4), where the definitions of "ephemeral" involve flow in response to wet weather and ground saturation (Virginia - Appendix E; West Virginia - Appendix F) and an evident channel (West Virginia; Appendix F). In Maryland, all nontidal wetlands designated as "blue line" wetland features should be buffered from forest harvesting operations (Table 4, Appendix B). Nontidal forested wetlands require buffers from forest harvesting in Virginia, Delaware, and Maryland (Table 4). The remaining Bay states do not have this requirement, although Pennsylvania does specify spring seeps and vernal ponds as having buffer requirements (Table 4). Nonforested wetlands, presumably interspersed with forests, receive no direct protection under forestry BMPs within the Bay states with the exception of marshes in Pennsylvania (Table 4, Appendix D) and New York (Appendix C). Of course many such wetlands are entitled to protection under federal statutes. From comparing these definitions of watercourses that require buffering, we find two conclusions. First, although we recognize the difficulty of technically defining and buffering ephemeral stream channels, further efforts to understand the magnitude of water pollution resulting from these potentially significant sources of sediment and nutrients is warranted. We suggest that more stringent consideration for protection of ephemeral channels would be wise. Second, using "blue line" features on readily available quad maps provides a relatively unambiguous definition of watercourses that should be buffered. It is not clear, however, whether this definition provides appropriate protection of water quality in actual field operations. Comparative studies are needed of the amount of buffer designated and degree of water quality preserved when necessary buffers are defined by "blue line" features versus more "on-the-ground" techniques (such as evident channel and flow when soil is saturated - West Virginia). In the absence of such studies, we recommend both techniques be used simultaneously as a conservative approach to protecting water quality.

All of the Bay states provide buffer width guidelines for streams that are recognized to be in need of buffering (Table 4). Thus buffers are generally specified for perennial and intermittent streams. Buffer width for ephemeral streams is specified only in West Virginia and Virginia. These buffer widths are influenced by factors such as slope (Table 5) and thus smallest and largest minimum buffer widths can be computed. These buffer widths generally range from 50 - 165 ft among the states' recommendations, with high similarity between perennial and intermittent streams (except for intermittent streams in New York). Maryland has notably larger high end minimums for haul roads, skid trails, log landings, humus disturbance, and clearcutting than the other states (Table 4). These larger minimum widths result from Maryland's more conservative slope buffering formula that provides for a 50 ft minimum plus four feet for each percent of slope. Thus, for a 50% slope, such a buffer width would be 250 ft. Of the forest operation disturbances mentioned in state BMPs, equipment operation is notable in that the Bay states, except Maryland, do not have a specified buffer width for it. However, in Virginia, haul roads and log landings are singled out for greater buffer widths if the watercourse supports trout.

Within streamside management zones, states vary in the types of forestry-related disturbances that are allowed and the width of buffer associated with these disturbance types (Table 4). For example, if a wide buffer is defined by some combination of stream type, disturbance type, and slope, a different disturbance may still occur within that buffer but will remain subject to its own buffer regulations. Almost uniformly the Bay states allow partial/selective harvesting within SMZs, with the stipulation of approximately 50 - 60% of crown cover or basal area be left. West Virginia, Pennsylvania, and New York allow clearcutting within stream management zones (Table 4). Of these three, both Pennsylvania and New York place limits on how close cutting can occur to the watercourse.

Wetland disturbances allowed during forest harvesting are highly variable among the Bay states (Table 6). However, two commonalities seem apparent. First, federal statutes and permitting procedures obviously apply to road building involving fill dirt, whether wetlands are located inside or outside an SMZ. Skid trails not requiring fill are discouraged although multiple exceptions are common. Both roads and skid trails are subject to similar recommendations as those generally applied in SMZs. Second, BMPs dealing with wetlands have numerous caveats that provide for "legitimate needs" and when "no practical option exists". Undoubtedly these caveats exist to facilitate the practical aspects of harvesting operations, but they do leave great latitude to on-site supervisors for final decisions on implementation. Overall, we feel that wetland BMPs probably should provide greater protection to wetlands that are not within SMZs, especially if they are directly linked to water courses. Otherwise, none of the Bay states stand out as particularly stringent or lax in their treatment of forestry BMPs for wetlands, although Maryland and Virginia specify no clearcutting of wetlands within the SMZ.

BMP Compliance

Since BMPs are "voluntary" measures in logging operations for all states in the Bay's watershed except Maryland, the extent and degree to which these practices are implemented is an important indicator of effectiveness. Only Maryland and Virginia have documentation of BMP compliance that resulting from independent evaluations carried out by state officials. This does not necessarily mean that other states in the Bay watershed do not carry out some level of inspection to gauge BMP compliance. However, telephone requests for this data indicated that no evaluation of compliance had been completed for Delaware, West Virginia, or Pennsylvania as of October 1996. New York did not respond to our request for this information. The proportion of Bay states formally assessing and reporting BMP compliance is similar to national trends; however, these efforts are becoming more common nationally (Ellefson and Chang 1995, Ellefson and Chang 1996, Waide 1994). Thus we would not be surprised to find that all states in the Chesapeake Bay watershed will soon issue such reports. We feel that this reporting is a positive step toward objective evaluation of BMP effectiveness.

To summarize current published BMP compliance within the Bay watershed, we obtained reports from both Virginia and Maryland describing the results of their efforts to quantify BMP implementation by logging operations in their jurisdictions (Koehn and Grizzel 1995, VDOF 1995, Austin 1995). These states used very different methodologies for the evaluation process. Maryland used five-member field survey teams consisting of a hydrologist (Department of Natural Resources), sediment control inspector (Maryland Department of the Environment), forester (Department of Natural Resources), soil specialist (from the local Soil Conservation District), and an industry representative; it was not possible to have the same team survey all sites. For the Maryland survey, 99 forest harvesting sites were inspected, which were randomly selected from a list of approved sediment and erosion control plans that were 10 - 350 ac in area and contained streams, ponds, lakes, or wetlands. These sites were also stratified across Maryland's counties and thus across physiographic provinces (Mountains - Allegheny Plateau, Ridge and Valley, and Blue Ridge; Piedmont; Upper Coastal Plain; Lower Coastal Plain). Each survey team member independently completed an evaluation form consisting of 23 yes/no questions that were designed to estimate whether the logging operation was in compliance with an array of specific BMPs. Thus the "degree" of compliance could not be assessed. For example, leaving a 90 ft buffer when 100 ft is recommended is much more acceptable than leaving a 20 ft buffer, but each is technically noncompliant. Written surveys were also used to poll 624 (17% return) licensed forest products operators and 221 (23% return) forest landowners. In contrast to Maryland, the State of Virginia apparently attempts BMP inspections for all timber harvests of five acres or more both during (interim visit) and after (final) harvest (VDOF 1995). Each visit is by a Virginia Department of Forestry (VDOF) employee, an industry forester, or a consulting forester, who determines if BMPs "are applied in sufficient quantity" and if BMPs "of appropriate type are applied". This comprehensive approach resulted in 2,862 BMP inspections in 1994, covering some 136,963 ac of harvested land. This effort is augmented by a small number of random "audits" conducted annually by VDOF personnel.

We found four key areas of forestry BMP implementation that can be reasonably compared between Maryland and Virginia: haul roads and skid trails, streamside management zones, log landings, and stream crossings. For haul roads and skid trails, Maryland reported 82% compliance (Koehn and Grizzel 1995) across all physiographic provinces. By Maryland's rating scheme (>89% - excellent; 80-89% - good; 70-79% - fair; <70% - low), this ranking is near the low end of the good range. Specific problem BMPs (<70% compliance) by province included: (1) Mountains - skid trail gradients (49%), skid trail drainage (54%), skid trail soil stabilization (50%), waterbars in haul roads (62%); (2) Piedmont - waterbars in haul roads (58%), skid trail soil stabilization (59%); (3) Upper Coastal Plain - waterbars in haul roads (59%), skid trail drainage (64%), skid trail soil stabilization (59%); and (4) Lower Coastal Plain - waterbars in haul roads (25%). In its compliance reporting, Virginia indicates the number and percent of sites with specific problems, as well as the degree of noncompliance by estimating the proportion of site disturbance that failed to meet recommended BMPs. For haul roads and skid trails the most frequently cited problems in 1994 (VDOF 1995) included: (1) skid trails with >15% slope (39% of all inspections), (2) skid trails without proper drainage (27%), (3) retired skid trails not properly seeded (27%), (4) skid trails with ruts >6 in. deep (20%), and (5) haul roads with >10%

slope (18%). Not surprisingly, slope problems are common on these lists. Slope problems in mountainous regions are particularly common, probably because of the amount of merchantable timber that would not be accessible or would be more costly to harvest should all BMP access restrictions be followed. The prevalence of drainage problems seems high, particularly because of the amount of research and demonstration that has been put into road construction and drainage (see "BMPs And Reduction Of Streamwater Sediment", this review). Soil stabilization ranks as a major problem throughout the state of Maryland (68% compliance), with particular problems in the mountains (65%), Piedmont (74%), and Upper Coastal Plain (66%). Most of the specific soil stabilization problems accrue from skid trails. Adequately seeding/stabilizing retired haul road and skid trails, as well as water control structures such as water bars and retired rolling dips, are also a major concern in Virginia (VDOF 1995).

Streamside management zones (SMZs) received an overall 83% compliance rating in Maryland (Koehn and Grizzel 1995). This rating dropped to 73% and 74% for the Upper Coastal Plain and Mountain provinces, respectively. Rates for the Piedmont (86%) and Lower Coastal Plain (91%) were notably higher. Soil repair (repair of severe soil disturbances created by harvesting) was the outstanding specific problem associated with SMZs in these provinces. Forest buffer retention (76%) and soil exposure (76%) were also notable in the Mountain province of Maryland. In Virginia (VDOF 1995), improper SMZs along perennial streams was reported for only 9% of the regular timber harvest inspections. However, during visits to 30 randomly selected logging operations as part of an independent 1994 statewide audit of the BMP effort, "SMZs were found to be lacking at 15 of the 30 sites..." (VDOF 1995).

Because of high truck and skidder traffic log landings and decks are often of great concern for water quality problems. Perhaps because of their localized nature and relative ease of compliance, log landings do not seem to be a problem in either Maryland or Virginia. Log landings and decks were in 90% compliance in Maryland (Koehn and Grizzel 1995), with uniformly high scores across all provinces and no notable specific problems. Specific concerns about log landings in Virginia focused on location within 50 ft. of an SMZ and slopes >5% not seeded after use, but both were reported as problems <10% of the time.

Perhaps the most prominent BMP problem for Maryland deals with stream crossings (Koehn and Grizzel 1995). Stream crossings overall have a 75% compliance rate in Maryland, with design (65%) and approach road drainage (35%) being the most specific problems. Notably, the number of stream crossings for sample sites was generally considered good to excellent. By provinces, water drainage aspects of stream crossings were complied with only 43% (Mountains), 36% (Upper Coastal Plain), 20% (Piedmont), and 0% (Lower Coastal Plain) of the time. This problem involved a consistent lack of "turnouts" in the approach of roads to the streams on the inspected sites; this BMP helps to prevent runoff from directly entering the stream from the road. Obviously the Maryland forestry BMP compliance report concluded that stream crossings was an area where "improvements could be made". Virginia has also found problems with BMPs that deal with stream crossings (VDOF 1995). Guidelines for the design and placement of structures, such as culverts, to enable heavy equipment to cross intermittent or perennial streams without increasing sedimentation are well-documented in Virginia's BMP manual for forestry operations (VDOF 1996). However, the 1994 field audit of randomly selected timber harvests found that most sites had undersized or incorrectly installed culverts. Temporary bridges have been suggested as a primary alternative for culverts (VDOF 1995).

Despite their different approaches, the compliance reports for Virginia and Maryland identified similar problems in rates of BMP implementation. These include both diffuse problems, such as location of skid trails, and point problems, such as stream crossings. This result suggests that (1) some BMPs are simply difficult to implement and meet compliance whether regulated or voluntary, and/or (2) Maryland's regulatory authority over BMPs and Virginia's voluntary BMP program have similar implementation problems. However, because of different methodologies for data collection and reporting, unassessed statistical rigor of the sampling protocols (at least not reported), and lack of tests for statistical significance of the compliance rates, it is difficult to directly compare these two reports. The discrepancy in Virginia with regard to results from regular reporting versus random surveys of SMZ compliance can be explained on a methodological basis. Regular, large-scale reporting on BMP compliance in Virginia apparently allows "close enough" or partially successful efforts to count as compliance. In comparison, the random inspections stringently apply BMP standards when making assessments of compliance. Not surprisingly, these different definitions of successful BMP application yield different results.

Evaluation Of Forestry Best Management Practice Effectiveness

Two factors make the task of evaluating effectiveness of forestry BMPs difficult. First, few such studies have actually been carried out. For example, we have found only one published study that attempts to test forestry BMPs within the CBW. Riekerk et al. (1989) noted a similar lack of BMP testing in the southern United States. Published reviews of regional BMP programs also indicate very little research in southeastern (Waide 1994), northcentral (Ellefson and Chang 1996), and western (Ellefson and Chang 1995) states on BMP effectiveness. Second, of the experimental studies that do test forestry BMPs, most actually address the effectiveness of a suite of BMPs, thus making quantitative judgments of individual BMPs impossible. Within these constraints, we examine the evidence that forestry BMPs help maintain water quality by sediment and nutrient reduction.

BMPs And Reduction Of Streamwater Sediment

Sediment production is widely regarded as the most serious water quality impact resulting from forest management (Douglass 1975). Thus multiple reviews of this subject for part or all of the eastern United States, but with different emphases, have been undertaken:

Forested wetlands -	Howard and Allen (1988),Shepard (1994)
Intensive harvests -	Hornbeck and Ursic (1979)
General harvesting practices -	Douglass (1975), Sopper (1975), Ursic and Douglass (1978)
Buffer zones -	Comerford et al. (1992), Neary et al. (1993)
Southern U.S. provinces -	Yoho (1980), Marion and Ursic (1993)
U.S. regional variation -	Patric et al. (1984)
East U.S. harvest/regeneration -	Stone et al. (1978)

These reviews span 19 yrs and, despite their differing emphases, draw heavily on a common literature base. Much of the referenced research in the eastern United States has been carried out at USDA facilities, primarily Coweeta Hydrologic Laboratory (NC), Fernow Experimental Forest (WV), and Hubbard Brook Experimental Forest (NH). None of these sites are within the CBW, yet collectively they bracket the watershed latitudinally. Notably, none of these sites occur in the Piedmont or R&V, although all are in mountainous areas that in some topographic respects resemble the R&V. Within the R&V significant work on forest management and sediment control has been carried out at the Leading Ridge Experimental Watersheds (PA), which represents the primary site within the CBW for research on water quality impacts of forest harvesting and forestry BMPs. In reviewing specific research results we will draw heavily on these sites and supplement with additional studies that either represent a particularly pertinent result or represent the Piedmont province.

The USDA's Fernow Experimental Forest (FEF), located in the Central Appalachians of West Virginia, has been the focus of several heavily cited studies that examine sediment loss from haul roads and skid trails. Kochenderfer and Aubertin (1975) used a paired watershed approach to examine the relative impacts of planned silvicultural versus "logger's choice" clearcuts (CC) on streamwater turbidity (Table 7). The primary objective of this study was to compare sediment loss from the road and skid trail systems developed by professional foresters and that developed when logging proceeds without trained oversight. Notable differences included grades of roads and skid trails, stream crossings (both number and construction), and placement of skid trails in relation to streambeds. Results clearly indicated that (1) compared to undisturbed control conditions, some minor (and probably negligible) increase in streamwater turbidity is inevitable even with sound road systems, and (2) unplanned road systems result in exceedingly high streamwater turbidity. The range of turbidity values for the "logger's choice" treatment also indicated pulses of sediment from unstable ground conditions during storm events. Such pulses were non-existent under the silvicultural cut and control conditions. Hornbeck and Reinhart (1964) and Kochenderfer and Helvey (1984) compared a control FEF watershed with four different types of forest harvests that also had unique water control BMPs (Table 7). As indicated by the stringency of the BMPs (Table 7), the combined use of waterbars, bridges, disturbed ground stabilization by revegetation, and the slope angle on which skid trails were allowed collectively exerted strong control over streamwater turbidity. Notably, of the selection cuts, the cut that removed greater numbers of trees (presumably requiring more log skidding and potentially more soil disturbance) also had a lower impact on turbidity because of more stringent BMPs. Weitzman and Trimble (1952) specifically examined skid trail construction characteristics and found a gradient of erosion rates from sections of skid trails that decreased as the quality of construction increased (Table 7). Patric (1980; see also Aubertin and Patric 1974) found no difference in stream turbidity under non-storm conditions for a control and a clearcut that had a 20 m stream buffer (diameter limit cut in dry weather), no machinery allowed in the buffer, and revegetation of disturbed sites following logging. However, storms produced notable differences in peak turbidity. Stream buffers were also the focus of Kochenderfer and Edwards (1991). They found increased sediment loss from two different forest harvesting treatments. These increases are difficult to distinguish from changes in the control watershed, a fact attributed largely to the stream buffer system (Kochenderfer and Edwards 1991). Trimble and Sartz (1957; not found in Table 7) provided recommendations concerning filter strip widths for forest roads on different slopes. The specific recommendations of Trimble and Sartz (1957) were rather subjective and the authors noted that the results may be only locally applicable.

Innovative research on road construction at Coweeta Hydrologic Laboratory (CHL) resulted in one of the most widely used best management practices - the broad-based dip, in which logging roads periodically slope outward to drain water from the road into the adjoining forest. Swift (1984) compared a time sequence of erosion for roads on two slopes (5% and 7%) when the same construction BMPs were applied to each (Table 7). BMPs that were applied included broad-based dips, no ditches on the upslope side, and brush barriers at the toe of road fills to help filter sediment from runoff. Swift (1984) does not cite specific controls for the absolute amount of sediment produced by the two sites in this study. However, it is clear that even relatively small differences in slope are important in determining sediment loss even when water and sediment control BMPs are used. Based on this work and the amount of harvested sites that can

TABLE 7. Summary of studies that test the effectiveness of forestry best management practices (BMPs) for sediment reduction in the eastern United States.

STATE	BMP	TYPE[1]	REP[2]	SEDIMENT EFFECTS OF TREATMENTS		REF
					Turbidity (JTU)	3
WV	Road	PW,E	No	Treatments	(Mean, Range)	
				Control	2 (0-25)	
				Silvicultural CC	6 (0-90)	
				"Logger's Choice" CC	490 (0-56,000)	
WV	Multiple (See treatments)	BA	No	Treatments	Max. Turbidity (JTU)	4
				Control	15	
				Selection Cut (> 5 in.) Skid trail <10% slope and away from streams, waterbars, bridges, some site stabilization w/ grass	25	
				Selection Cut (>11 in.) Skid trail <20% slope and away from streams, waterbars, bridges	210	
				Diameter Limit (>17 in.) "Logger's choice" w/ waterbars on skid trials	5,200	
				Commercial CC "Logger's choice"	56,000	
WV	Skid road slope; Waterbars	E	Yes	Skid Road Type[17]	Erosion	5
				High Order	52 ft^3/100ft	
				Good	65	
				Fair	70	
				Poor	91	

(Continued)

Table 7. (Continued)

STATE	BMP	TYPE[1]	REP[2]	SEDIMENT EFFECTS OF TREATMENTS	REF
WV	Stream buffer; Roads	PW, E	No	Sediment (lb/ac) Treatment — Pre-treat. — Post-treat. Control — 29 — 86 CC with 66' buffer — 238 — 280 14" Diameter limit cut, roads finished before cutting, 160' stream buffer (cut), no road/machinery in buffer — 48 — 182	6
WV	Stream buffer; Road grade; Revegetation	PW,E, BA	No	Treatment — Sediment (NTU) Control — <2 (Storm max. = 40) CC — <2 (Storm max. = 550)	7
NC	Haul road stabilizing and slope	OB	Yes	Sediment moved greater distance on steeper slopes; Grass vegetation on road fills, brush barriers, and culverts effective in lowering distance sediment moved, but interacted with slope	8
NC	Road dips, no ditches, barriers of brush	BA	No	Time Sequence — Erosion (T/ac/mo): 7% slope — 5% slope Postconstruction — 1.18 — .24 Winter (no cover) — 1.77 — 1.13 Logging — 1.48 — 1.10 Grass + gravel — .62 — .19 Grass established — .08 — .01	9

(Continued)

Table 7. (Continued)

STATE	BMP	TYPE[1]	REP[2]	SEDIMENT EFFECTS OF TREATMENTS			REF
NH	Multiple (See treatments)	PW, LTM	No	Treatments	Erosion (kg/ha/yr)		10
				Control	54 (sd=44) 31 (sd=20) 23 (sd=20)		
				CC, leave wood, herbicide, no filter strip	64		
				Whole-tree harvest, filter strip, no trucks, skid trails w/ dips & waterbars	82 (range=6 - 208)		
NH	Buffer strip	PW, LTM	No	Treatments	Stream Turbidity (JTU)		11
				Strip cut & leave buffer strip	Samples <1JTU = 93%		
				Block CC & no filter strip	Samples <1JTU = 88%		
NH	Buffer strip	2 sites	No	Treatments	Stream Turbidity (JTU)		12
				Control	<1		
				Whole-tree harvest	<1		
NH	Roadside filter strips	OB	NA	Demonstrated that the distance of sediment transport from roads increases with slope; Estimated required filter strip widths			13
SC	Prescrib. burn	PW, E, BA	Yes	Treatments	Erosion (kg/ha/yr)		14
					Pre-Burn	Post-Burn	
				Control	18.1	43.6	
				Burned	21.7	31.7	

(Continued)

Table 7. (Continued)

STATE	BMP	TYPE[1]	REP[2]	SEDIMENT EFFECTS OF TREATMENTS			REF
SC	Haul roads and decks outside watersheds; slash left in place; gravel road surface; low soil disturb.	PW, E BA	Yes		Erosion (kg/ha/yr)		15
				Sampling Time	Control	Harvest	
				Calibration 1	26.8	41.5	
				Calibration 2	24.3	73.9	
				After Harvest 1	19.6	151.1	
				After Harvest 2	3.0	23.4	
				After Harvest 3	8.6	49.1	
PA	Multiple[18]	PW,E, LTM	No		Suspended Sediment (mg/l) Mean and range for		16
				Treatment	1977	1978	
				Control	1.7 (.2-8.6)	5.1 (.3-33.5)	
				CC,Herbicide	10.4 (2.3-30.5)	78.7 (1.8-38.0)	
				CC	5.9 (.3-20.9)	9.3 (.2-76.0)	

1 Type of study: LTM - long-term monitoring, BA - before and after treatment measurements, PW - paired watersheds, OB - observational, E - experimental
2 Replication in study design
3 Kochenderfer and Aubertin (1975)
4 Hornbeck and Reinhart (1964)
5 Weitzman and Trimble (1952)
6 Kochenderfer and Edwards (1991)
7 Patric (1980)
8 Swift (1986)
9 Swift (1984)
10 Martin and Hornbeck (1994)
11 Hornbeck et al. (1987)
12 Hornbeck et al. (1986a)
13 Trimble and Sartz (1957)
14 Douglass and Van Lear (1983)
15 Van Lear et al. (1985)
16 Lynch et al. (1985)
17 High order - skid trails <10% slope, waterbars as needed; Good - skid trails <20% slope, waterbars at 2 chain intervals; Fair - No slope restriction on skid trails, waterbars > 2 chains apart; Poor - No slope restriction on skid trials, no waterbars
18 BMPs included 100 ft buffer, professional inspections, no skidding over streams, no slash within 25 ft of perennial/intermittent streams, skid trails professionally designed, log landings at least 300 ft. from streams, all roads and skid trails properly retired, no logging in wet conditions, fertilizing and seeding of all roads and skid trails

be used for skid trails, roads, and log landings (Kochenderfer 1977), studies that define the effect of road and skid trail slope (e.g. Hornbeck and Reinhart 1964) are particularly important. Many BMPs specified within the Bay states relate to allowable slope for roads and skid trails. The results of Swift (1984) also point out the importance of timing in harvesting and establishing ground cover relative to season. Again, several Bay states have BMP recommendations concerning wet weather logging and promptness of revegetation. An observational study by Swift (1986) also emphasized the interactions among road slope, stabilization efforts through revegetation, and brush filters on road fills.

Martin and Hornbeck (1994) used paired watersheds (no replication of treatment watersheds) to examine erosion rates from an experimental clearcut that minimized soil disturbance by felling trees and leaving them on site and an intensive whole-tree harvest that employed multiple BMPs but by its mechanized nature caused more wide-spread soil disturbance (Table 7). As expected, the clearcut increased erosion, but not considerably more than the control watershed. Intensive harvesting further increased erosion (Table 7). However, Martin and Hornbeck (1994) suggested that the BMPs employed prevented erosion from increasing proportionately with soil disturbance. Hornbeck et al. (1987) found little difference in streamwater turbidity from a strip cut with a buffer strip (15 - 25 m) and a block clearcut leaving no buffer (Table 7). This lack of effect prompted the conclusion that "northern hardwood ecosystems have an inherent resistance to erosion that can withstand cutting disturbances so long as the forest floor is not abused" (Bormann et al. 1974). An important aspect of not "abusing" the forest floor was implementation of BMPs, specifically placement of log landings outside the watershed, tree tops and branches removed from the stream, skidder trails along ridges away from streams, properly installed culverts at stream crossings, and waterbars placed on skid trails immediately after logging. Many of these BMPs are recommended by the Bay states. Hornbeck et al. (1986a) found similar results for stream turbidity when comparing buffer strip effectiveness between control and whole-tree harvested watersheds (Table 7). Two peaks of stream turbidity (2,200 and 3,300 JTU) for the harvested watershed occurred when a road culvert failed, thus highlighting the importance of proper culvert installation which is often detailed in BMP manuals. As noted earlier, Trimble and Sartz (1957) suggested that degree of slope plays an important role in the required width of roadside filter strips.

Applications of prescribed burning, used to control hardwood understory encroachment in pine stands, are defined in the BMP manuals of Virginia, Maryland, and Delaware. In the South Carolina Piedmont, Douglass and Van Lear (1983) found that prescribed burns had no detectable effect on erosion rate compared to paired control watersheds (Table 7). Further, no effect was found after repeated burns. Using these same paired watersheds, Van Lear et al. (1985) found that clearcutting the experimental watersheds resulted in a significant increase in soil export during the first year after harvest (Table 7). Erosion decreased rapidly and was not significant in years two and three after harvest. BMPs were applied to all harvested watersheds, as described in Table 7. Without an experimental design that included watersheds harvested <u>without</u> these BMPs, it is difficult to distinguish BMP effects from minor harvesting effects.

The sole published experimental study of BMP effectiveness within the CBW occurred in Pennsylvania at the Leading Ridge Experimental Watersheds. Research activities and results from different phases of the work at Leading Ridge have been published in multiple places (Corbett et al. 1975, Corbett et al. 1978, Mussallem and Lynch 1980, Lynch and Corbett 1989, Lynch and Corbett 1990, Lynch and Corbett 1991). Three watersheds form the core of the Leading Ridge work - a control, a commercial clearcut (1976-1977) with BMPs, and a progressively cut (lower slope - 1967, middle slope - 1972, upper slope and ridge top - 1976) watershed that was also herbicided (1974 and 1977) to prevent regrowth of cut areas. Lynch et al. (1985) reported annual averages and ranges of stormwater suspended sediment concentrations for 1977 and 1978 (Table 7). The commercial clearcut showed little response in sediment concentration from cutting, and the clearcut-herbicide treatment displayed a very significant increase in sediment concentration following herbicide application. Although a common management practice in many of the Bay states, repeated herbicide treatments are uncommon and can apparently cause destabilization of stream channel banks through lack of vegetation (Lynch et al. 1985). In the case of the Leading Ridge commercial clearcut, the stringent enforcement of BMPs apparently alleviated a any large increases in stormwater sediment concentration. However, the range of values for the commercial clearcut suggests that unstable soil sites do exist as a result of harvesting. Lynch et al. (1985) attribute large sediment pulses to tree blowdown along an intermittent stream channel where a narrow buffer was unable to withstand wind velocities within the clearcut. Lynch et al. (1985) also cautioned that decreased transpiration after cutting can result in intermittent stream channels becoming perennial which exacerbates such problems as windthrow along intermittent stream buffers. Long-term monitoring of the commercial clearcut indicates streamwater turbidity levels elevated above the control and with greater annual pulses than the control for about 12 yrs (Lynch and Corbett 1990). Notably, the Leading Ridge experiments lack replication, and the BMP test with the commercial clearcut lacks a paired watershed with harvesting and no BMPs to separate harvesting and BMP effects.

Overall, the studies reviewed here form much of the basis for forestry BMPs that are recommended for sediment control in the Bay states. Although many of these studies are rather dated, their results remain pertinent. Several of the more recent studies take advantage of the experiments and long-term monitoring data from older study sites located in long-term research areas. We are aware of only two current experiments to measure sediment or nutrient control by forestry BMPs. One is being conducted by the Maryland Forest Service on private land at Sugarloaf Mountain, a site generally representative of the Ridge and Valley province. This project is relatively new at this time. The other, being collaboratively carried out by the Virginia Department of Forestry, Virginia Tech, and the Chesapeake Corporation, is in the Nomini Creek watershed in Virginia. Published results were not found for this study. We have concern that other studies of the effectiveness of suites of BMPs are not ongoing in order to examine the effects of new technological methods of implementation, changes in forest harvesting practices that would have different impacts on soils, and new combinations of BMPs which vary among the Bay states. The general lack of basic data on BMP effectiveness for forestry sediment control within the CBW is also of concern, although the largely physical processes of sediment loss and control should be more readily extrapolated than the biological controls on nutrients. New studies that test sediment control by forestry BMPs should use complete experimental designs with replicated controls, treatments with BMPs, and treatments without BMPs.

BMPs And Reduction Of Streamwater Nitrogen And Phosphorus

Multiple studies have shown that forest harvesting and associated soil disturbance increase the potential for nutrient loss from harvest sites to hydrologically associated streams (Pierce et al. 1972, Aubertin and Patric 1974, Johnson et al. 1982, Hornbeck et al. 1986b, Martin et al. 1986, Hornbeck et al. 1987, Mann et al. 1988, Hornbeck et al. 1990). This loss can be in either particulate or dissolved inorganic and organic forms. For dissolved nutrients, inorganic forms of nitrogen (particularly nitrate) have received the greatest attention. Forest harvesting alters microsite soil conditions to favor nitrification (Vitousek and Matson 1984, 1985) and thus increased soil concentrations of highly soluble nitrate. Loss of nitrate from harvested forests is exacerbated by decreased leaf area, decreased transpiration, and increased runoff (Hibbert 1966, Swank 1988). Best management practices can reduce nitrate runoff from forest management operations by (1) encouraging immobilization by plants and microbes *in situ*, or (2) removal from surface or ground water flowing from the harvested site through immobilization or denitrification. On-site immobilization is encouraged by increasing precipitation infiltration, ensuring rapid revegetation, and retaining logging slash on-site as a microbial decomposition substrate with a high carbon:nutrient ratio. Streamside management zones (or riparian buffers, filter strips, etc.) are generally recommended as sites for immobilization and denitrification when nitrate flows from the harvesting site hydrologically. Multiple BMPs recommended by the Bay states take these actions either explicitly or implicitly.

Streamside management zones (SMZs) are ubiquitous in forestry BMP recommendations for nutrient and sediment filtering, and also to shade streams and to provide organic matter to stream ecosystems. Most research relating to the effectiveness of SMZs for filtering nutrients has focused on forest buffers in a landscape of multiple landuses, not as uncut streamside forest left as part of a forest management operation. Reviews of buffer strip effectiveness reflect this emphasis. For example, Osborne and Kovacic (1993) briefly summarized the use of SMZs for water quality restoration. Of the studies cited by Osborne and Kovacic (1993), all four references concerning riparian effects on stream temperature, three of five for sediment control, and none of seven for nutrient filtering by forests were drawn from forest management/harvesting projects. Each of the nutrient filtering studies cited by Osborne and Kovacic (1993) have upslope agriculture as the source of nutrients. In their review, Osborne and Kovacic (1993) found that forest buffers can reduce subsurface water nitrogen by 40-100%, reductions of phosphorus in subsurface water show no clear pattern, riparian areas of 30-50 m in width reduce surface water nitrate 79-98%, and buffers of 16-50 m in width reduce surface water phosphorus by 50-85%. Kuenzler (1989) examined the ability of southeastern United States forested wetland/riparian systems to filter sediment and nutrients in runoff from agricultural sources. For total nitrogen and total phosphorus, respectively, Kuenzler (1989) reported removals of 89 and 80% (Peterjohn and Correll 1984), 22 and 37% (Yarbro et al. 1984), approximately 80 and 81% (Chescheir et al. 1987), 68 and 30% (Lowrance et al. 1984), and 26 and 41% (Kemp and Day 1984). The proportion of these five watersheds in active agriculture ranged from 32 to near 100%. Working on the Maryland Coastal Plain, Peterjohn and Correll (1984) found an annual dissolved surface water nitrate nitrogen concentration of 4.45 mg/l entering a riparian forest from upland agriculture. Annual concentrations in groundwater entering the riparian forest ranged from 6.76 to 7.4 mg/l of nitrate. These concentrations were reduced to 0.941 mg/l for surface water and 0.101 to 0.764 mg/l for groundwater leaving the riparian forest. Collectively, these studies clearly indicate the potential of riparian forests to filter nitrogen and phosphorus from upland agricultural runoff. Several small watershed studies in the eastern United States provide forest data for comparison to agricultural runoff nitrate concentrations. Swank (1988) reported 0.15 mg/l as the peak nitrate concentration of streamwater leaving a completely clearcut (with timber removed) watershed. The control watershed streamwater nitrate was 0.003 mg/l (Swank and Waide 1988). These whole-watershed streamwater values represent combined surface and groundwater flow. Lynch and Corbett (1990) found somewhat higher control and peak clearcut (harvested with stringent BMP enforcement, including SMZ establishment) streamwater nitrate concentrations in Pennsylvania: 0.03 and 0.4 mg/l, respectively. In addition, Bormann et al. (1968) and Likens et al. (1970) reported a control watershed streamwater nitrate concentration of approximately 2.0 mg/l in New Hampshire. Logically, nitrate concentrations in runoff from forest watersheds, whether harvested or not, are notably lower than those from agriculture.

Comerford et al. (1992) reviewed the effects of buffer strips for decreasing sediment, nutrient, and pesticide transport from silvicultural operations. Finding that "the literature that specifically examines the function of buffer strips [for silvicultural operations] to protect aquatic environments is sparse", Comerford et al. (1992) largely used studies from agricultural watersheds in Georgia, North Carolina, and Maryland to support the effectiveness of forest buffers for nutrient filtering. Their single example from a silvicultural operation was the work of Martin and Pierce (1980) at Hubbard Brook Experimental Forest (HBEF). Comerford et al. (1992) concluded that forest buffers in agricultural landscapes were effective at reducing nitrogen loading to streams, but much less efficient at phosphorus removal. Martin and Pierce (1980) found that forest buffer strips left during forest harvesting reduced the mean and maximum amounts of nitrate in streamwater, as well as the time required to return to background levels. Specific to the CBW, Lowrance et al. (1995) reviewed the evidence for nutrient filtering by Coastal Plain, Piedmont, and RAV forest riparian buffers. These authors found the greatest number of such studies for the Coastal Plain (all referring to agricultural runoff); very limited data on nutrient filtering by riparian forests for the entire Piedmont (again citing only agricultural runoff studies) and none for the CBW Piedmont specifically; and one study of a riparian buffer filtering nutrients from a forest clearcut in the RAV (Lynch et al. 1985, Lynch and Corbett 1990). Thus the literature consensus is that SMZs are effective in filtering nutrient from agricultural runoff. Because the magnitude of nutrient concentrations and fluxes leaving agricultural systems are generally much greater than those generated by forest harvesting, it seems logical that SMZs implemented as forestry BMPs would be effective at filtering most of the nutrients from forestry runoff. This simplistic assumption does not consider the differential effects of hydrogeologic conditions, topography, and soil erodibility. These considerations are all important because forests are not evenly distributed across the CBW, but are more common in mountainous areas (Seagle et al., in press) and on steeper slopes less conducive to agriculture. Collectively, Karr and Schlosser (1977, 1978), Comerford et al. (1992), and Lowrance et al. (1995) emphasize the potential complexity of geologic, hydrologic, climatic, soil, and biological (including forest species composition and vegetative structure) interactions in SMZ function. The resulting potential difficulty of site-specific predictions for SMZ effectiveness, however, does not invalidate the recommendation of SMZs as a forestry BMP. Comerford et al. (1992) suggest further research needs for understanding effectiveness of silvicultural SMZs as (1) buffer strip width, (2) soil erodibility, (3) slope of watershed and buffer area, (4) impacts of different hydrologic regimes, (5) size of harvest, (6) type of harvest, (7) type of harvesting equipment used, and (8) site preparation methods. In addition, recent publications that extend the theory of nitrogen saturation (Aber et al. 1989) to riparian zones (Groffman et al. 1992, Hanson et al. 1994) suggest that further research also be aimed at quantifying potential rates of saturation, the effects of SMZ forest management on vegetation nitrogen uptake (Lowrance et al. 1984), and the hypothesis that disturbance of SMZs can release large pulses of nitrogen (Gardner et al. 1996).

Our literature search revealed few papers in the primary literature for the eastern United States that bear on the research needs expressed by Comerford et al. (1992). Although multiple research harvests employing various sets of BMPs have been carried out at USDA facilities, such as Coweeta Hydrologic Laboratory (CNL), Fernow Experimental Forest (FEF) and Hubbard Brook Experimental Forest (HBEF), these experiments do not have a harvest treatment <u>without</u> BMPs against which to measure BMP success. Although such a harvest (often referred to as "logger's choice") was carried out at FEF in the late 1950s, we were not able to locate measurements of nitrate flux from the watershed, although information on water yields (Reinhart 1964) and sediment/water turbidity (Hornbeck and Reinhart 1964, Kochenderfer and Aubertin 1974) from this experiment have been published.

TABLE 8. Summary of studies that test the effectiveness of forestry best management practices (BMPs) for nutrient reduction in the eastern United States.

STATE	BMP	TYPE[1]	REP[2]	NUTRIENT EFFECTS OF TREATMENTS					REF
					Nitrate (kg/ha/yr)				
WV	Buffer; Roads; Reveg.	PW, E, BA	No	Time	Control	Clearcut			3
				Preharvest	.7	.7			
				During harvest	.5	2.8			
				After - 1 Year	1.0	2.2			
				After - 2 Years	1.2	1.9			
				After - 3 Years	1.8	2.1			
				After - 4 Years	3.3	4.5			
				After - 5 Years	2.9	2.6			
				After - 6 Years	2.1	1.5			
NH	Buffer	PW, BA	No		Nitrate (mg/l)				4
				Time	Control	Strip Cut	Block CC		
				Preharvest	2.1	2.4	.4		
				After - 1Year	1.4	5.4	13.1		
				After - 5Years	2.3	1.9	.3		
NH	Buffer strip	2 sites	No	Treatments	Nitrate (mg/l)				5
				Control	----				
				Whole-tree harvest	0- 6 mo: 1-3 < control				
					7-18 mo: <1 > control				
NH	Buffer patterns	E	Partial	Treatment	Nitrate (mg/l)				6
					Year: 1	2	3	4	
				Clearcut	10.6	17.6	10.5	3.5	
				70%CC, B	4.8	8.8	----	----	
				50%CC (upper)	8.1	11.3	6.4	----	
				50%CC (lower)	8.1	5.2	4.1	----	
				35%CC (lower), B	6.8	3.4	1.0	----	
				Strip Cut, B	3.7	5.5	5.0	3.1	

(Continued)

Table 8. (Continued)

STATE	BMP	TYPE[1]	REP[2]	NUTRIENT EFFECTS OF TREATMENTS	REF
VA	Site Prep	PW,E	No	See below	7

Treatments	Soil Solution (mg/l) NO_3	NH_4	PO_4
Control	.01	.08	.008
Harvest - Clearcut	.60	.22	.016
Site Preparation			
Control	.18	.57	.01
Chop & Burn	.32	.66	.005
Shear & Disk	1.78	.95	.012
Shear, Rake, Disk	4.75	.86	.012

STATE	BMP	TYPE[1]	REP[2]	NUTRIENT EFFECTS OF TREATMENTS	REF
GA	Site Prep	PW,E	No	See below	8

Treatments	Watershed	Soil Solution (mg/l) NO_3	Total P
Calibration	Control	.16	.22
	Harvested	.05	.20
Harvest	Control	.07	.21
	Harvested	.02	.19
Roller-chop	Control	.15	.24
	Harvested	.03	.19
Planting	Control	.11	.58
	Harvested	.02	.48
Recovery	Control	.11	.66
	Harvested	.02	.75

STATE	BMP	TYPE[1]	REP[2]	NUTRIENT EFFECTS OF TREATMENTS	REF
SC	Haul roads and decks outside watersheds; slash left in place; gravel road surface; low soil disturb.	PW, E BA	Yes	See below	9

Time	Nutrient	Soil Solution (mg/l) Harvest	Control
Calibration 1	NO_3	.04	.05
	NH_4	.05	.05
	PO_4	.008	.005
Calibration 2	NO_3	.05	.04
	NH_4	.05	.07
	PO_4	.019	.021
After Harvest 1	NO_3	.03	.02
	NH_4	.01	.01
	PO_4	.005	.003
After Harvest 2	NO_3	.05	.22
	NH_4	.05*	.13
	PO_4	.016	.022
After Harvest 3	NO_3	.01	.03
	NH_4	.01	.04
	PO_4	.013	.020

(* = significant at 0.05)

(Continued)

Table 8. (Continued)

STATE	BMP	TYPE[1]	REP[2]	NUTRIENT EFFECTS OF TREATMENTS				REF
SC	Prescrib. burn	PW, E, BA	Yes	Nutrient	Time	Treatment (kg/ha/yr)		10
						Burn	Control	
				NO_3	Preburn	.026	.028	
					Burn 1	.069	.058	
					Burn 2	.058	.050	
				NH_4	Preburn	.049	.036	
					Burn 1	.078	.057	
					Burn 2	.064	.071	
				PO_4	Preburn	.012	.004	
					Burn 1	.009	.004	
					Burn 2	.027	.023	
PA	Multiple[12]	PW,E	No	Time		Nitrate (mg/l)		11
						Control	Clearcut	
				Preharvest		.03	.04	
				Postharvest				
					Year 1	.11	.40*	
					Year 2	.05	.28*	
					Year 3	.05	.14*	
					Year 5	.05	.12*	
					Year 7	.10	.10	
					Year 9	.05	.08*	
					Year 11	.11	.09*	
				(* = significantly different from control)				

1 Type of study: LTM - long-term monitoring, BA - before and after treatment measurements, PW - paired watersheds, E - experimental
2 Replication in study design
3 Patric (1980)
4 Hornbeck et al. (1986b)
5 Hornbeck et al. (1986a)
6 Martin and Pierce (1980)
7 Fox et al. (1983)
8 Hewlett (1979)
9 Van Lear et al. (1985)
10 Douglass and Van Lear (1983)
11 Lynch and Corbett (1990)
12 BMPs included 100 ft buffer, professional inspections, no skidding over streams, no slash within 25 ft of perennial/intermittent streams, skid trails professionally designed, log landings at least 300 ft from streams, all roads and skid trails properly retired, no logging in wet conditions, fertilizing and seeding of all roads and skid trails.

Patric (1980) compared nitrate flux from a control and a clearcut watershed at FEF (Table 8). Best management practices implemented for the clearcut included roadwork completed before harvesting, roads >20 m from streams, 100 m spacing of skid roads, implementation of road drainage structures, revegetation of log landings, restricted harvesting near the stream during wet weather, and a 3.0 ha SMZ where only the largest trees were cut. Nitrate export clearly increased during harvest and remained elevated for at least one year thereafter. This study demonstrates the relatively low export rates of nitrate commonly found in studies of forest harvesting and the inability of rather extensive BMPs to completely alleviate nitrate loss, but does not have a harvest treatment without BMPs to distinguish BMP from harvesting effects.

To examine the role of vegetation in streamflow and nutrient retention an experimental watershed was clearcut (without removal of vegetation) and sprayed with herbicide for three years (Bormann et al. 1968, Pierce et al. 1972) at HBEF. As a result, streamwater nitrate concentration rose from approximately 2 mg/l to as high as 90 mg/l. Over the three years of vegetation suppression, streamwater nitrate concentrations averaged approximately 60 mg/l and annual nitrogen export averaged about 114 kg/ha (Pierce et al. 1972). This export rate is not truly reflective of harvesting without BMPs because downed trees were left on site, soil disturbance was minimized, and revegetation was not allowed to immobilize mineral nitrogen. Nonetheless, it does reflect a worst-case scenario and is the best available analog for forest harvesting without BMPs at HBEF. Hornbeck et al. (1986b) reported a comparison of stream nitrate concentrations for control, strip cut, and block clearcut watersheds at HBEF (Table 8). For the progressive strip cut, the watershed was harvested over a four-year period leaving a buffer strip intact along the stream. The block clearcut left no buffer. Judged by the control watershed, streamwater nitrate concentrations in both the clearcut and strip cut watersheds increased after harvest. However, even without a stream buffer, the block clearcut only reached 13.1 mg/l before declining by the fifth year after harvest. Hornbeck et al. (1986a) harvested approximately 40% of a watershed by whole-tree harvesting, leaving a 10-30 m buffer along the stream (Table 8). Stream nitrate concentrations increased only slightly after the harvest, peaking at about 6.5 mg/l. Of the New Hampshire studies, Martin and Pierce (1980) provide the best direct evidence for SMZ effectiveness in reducing nitrate loss (Table 8). By comparing different intensities of clearcutting and buffers, they found that watersheds without stream buffers had higher nitrate concentrations than watersheds with buffers, even if those with buffers were more severely cut. Collectively, these studies present reasonable, even if often indirect, evidence that the SMZs recommended by the Bay states are effective in nitrate filtering. Obviously, the exact degree of effectiveness cannot be estimated, but certainly none of the harvest treatments approached the worst-case nitrate loss reported by Bormann et al. (1968).

Site preparation is commonly practiced in the Piedmont physiographic province of the Bay states, and guidelines are included in the BMP manuals of Virginia, Maryland, and Delaware. Because of potentially intense soil disturbance during site preparation, effects on soil nitrogen transformations are important. Vitousek and Matson (1984,1985) examined the impacts of forest harvesting and site preparation practices on soil nitrogen transformations and losses in the North Carolina Piedmont. Their results indicated that harvesting resulted in increased nitrogen mineralization and nitrification, but no increase in soil nitrate pools or losses. Site preparation that included removal of logging slash greatly increased both nitrate pools and losses, suggesting that microbial immobilization is a primary mechanism for nitrogen retention following harvesting. Herbicide application to prevent immobilization by regrowing vegetation exacerbated this effect somewhat (Vitousek and Matson 1985). In addition, a higher intensity of site preparation (chopping versus shear, pile and disk) also increased mineralization and nitrification rates (Vitousek and Matson 1985). Fox et al. (1983) examined the effects of harvesting pine/oak-pine and three different levels of site preparation intensity in preparation for planting of pines in the southwestern Piedmont of Virginia (Table 8). The experimental watersheds had ephemeral drainages and their results included only soil solution nutrient concentrations. Harvesting increased the soil solution concentrations of nitrate, ammonium, and phosphate (Table 8). Also, over the first year of the experiment, increasing degrees of site preparation intensity showed a very strong influence on nitrate concentration, a potential effect on ammonium, and no effect on phosphate. No further publications on this experiment were located by our literature search. In another study of site preparation effects on the Piedmont of Georgia, Hewlett (1979) found no temporal trend in soil solution nitrate on control or harvested watersheds (Table 8). In contrast, soil solution phosphate apparently increased during the planting and subsequent growth/recovery period for both control and harvested sites. Thus no effect of harvesting or site preparation was found in this study.

The effect of prescribed burning on nutrient export (Douglass and Van Lear 1983) and harvesting impacts on soil solution nutrients (Van Lear et al. 1985) were studied at the same sites in the South Carolina Piedmont (Table 8). No discernable impact of repeated prescribed fire was found on nitrate, ammonium, or phosphate export. Except for relatively minor volatilization of nitrogen from the forest floor, Richter et al. (1982) and Binkley et al. (1992) reached a similar conclusion. In the harvesting experiment, BMPs included keeping haul roads and log decks outside the watershed being harvested, surfacing roads with gravel, and protecting the soil by minimizing disturbance and leaving logging slash. Only one significant difference in soil solution chemistry was found (Table 8), but no trends were apparent. As with many other forest harvesting studies that include BMPs, it was not the original intention of the experiment to test the effectiveness of the BMPs.

The Leading Ridge watersheds in Pennsylvania represent the only site of forestry BMP testing within the Piedmont or R&V of the CBW (Table 8). Lynch and Corbett (1990) reported on the long-term results of a paired watershed experiment at Leading Ridge which involved clearcutting a watershed with very stringent BMPs. An increase in streamwater nitrate concentration was apparent for the experimental watershed the year after harvest, with the impact extending for multiple years. No experimental treatment of harvesting without BMPs was carried out.

These series of experiments establish that forest harvesting, with the use of recommended BMPs, limits nutrient (particularly nitrate) loss to surface water. This point is difficult to dispute despite the lack of appropriate experimental treatments and replication for virtually all of these studies. Thus we consider recommended forestry BMPs to be effective in helping control non-point source nutrients. However, at least over the short-term, elevated levels of nitrate are lost from harvest sites, and without including a harvest treatment without BMPs or having some reasonable analog, the degree of BMP effectiveness cannot be calculated.

Assessing Regional Applicability Of BMPs

Because of the scarcity of studies that test BMP effectiveness, especially within the Piedmont and R&V, we have resorted to a more general assessment of BMP effectiveness in this review. However, the hydrogeologic differences between and within the Piedmont and R&V, which were summarized by Lowrance et al. (1995), make clear the difficulty of confidently extrapolating the effectiveness or usefulness of any particular BMP over an area as large as the Chesapeake Bay watershed. A specific example common to the forestry BMPs of all the Bay states is the recommendation that SMZ width increase with slope. Undoubtedly this policy is effective in many areas. However, this BMP may not increase nutrient filtering effectiveness in portions of the Piedmont or R&V where water infiltration is high, water flow paths are deep, and there is extensive transmittal of groundwater directly to the stream channel from the hyporheic zone. This example also points out the potential for conflicts in managing for different aspects of water quality - while nutrient filtering may not increase with SMZ width in this example, sediment filtering might.

Another concern for BMP extrapolation is spatial variation in forest ecosystems within the CBW. For example, Corbett et al. (1978) examined data on nutrient loss from watersheds in the eastern United States and proposed a north to south trend of decreasing nutrient leaching. Stone et al. (1978) hypothesized that this gradient reflects differences in total soil nitrogen that would be available for mineralization and export after disturbance. Perhaps contributing to these soil differences are gradients in forest vegetation types within the CBW. Based on the U.S. Forest Service's (USFS) Forest Inventory and Analysis (FIA) data, there is wide variation in regional forest composition across the CBW (Figure 1). From these gradients and regional contrasts, one can hypothesize that BMPs should be tailored to forest ecosystem types, similar to Lowrance et al.'s (1995) description of tailoring SMZs to hydrogeology. This application of BMPs should maximize their effectiveness and perhaps minimize cost, but certainly would require more information on how specific BMPs interact with local physical and ecological conditions. Without this detailed information, there needs to be a basis for larger-scale generalization.

The ecoregion concept reflects the combination of geologic, soil, climatic, and biological parameters that need to be considered in BMP effectiveness (Karr and Schlosser 1977,1978; Comerford et al. 1992; Lowrance et al. 1995). Using Bailey's ecoregion delineation (Bailey 1995), ten ecoregions occur in the CBW (Figure 2) and four encompass the Piedmont and R&V: (1) the Northern Ridge and Valley, (2) the Blue Ridge Mountains, (3) the Northern Appalachian Piedmont, and (4) the Southern Appalachian Piedmont. We suggest that ecoregion boundaries can be used as a first approximation of how directly applicable a particular BMP or suite of BMPs would be. For example, because the BMP experiment at Leading Ridge (Lynch and Corbett 1990) was located in the Pennsylvania R&V, these results might be extrapolated to the entire Northern Ridge and Valley Ecoregion.

Multiple refinements to this approximation are possible. Using Leading Ridge as an example we consider two: forest composition and hydrologic units. Leading Ridge is largely a mixed oak forest (J.A. Lynch, personal communication), with ridgetops, upper slopes, and lower slopes being dominated by chestnut oak (Quercus prinus), red oak (Q. rubra), black oak (Q. velutina), and white oak (Q. alba). Eastern hemlock (Tsuga canadensis) and white pine (Pinus strobus) are most common in the bottomland coves. Although similar oak species dominate the vegetation of the R&V, notable variation in forest type is found within this ecoregion (Figure 1). Attempting to tailor BMPs to individual stand composition would be unacceptable. However, the vegetation types of smaller subdivisions of the R&V that are physically or ecologically important can readily be characterized using FIA data, and the applicability of BMPs reassessed at that scale. Because of the importance of spatial nutrient fluxes within the CBW, and thus cumulative impacts of nitrogen non-point source pollution, we subdivided the R&V into the hydrologic units used in the U.S. Environmental Protections Agency's Bay watershed model (Linker et al. 1994). For each of these units we calculated the percentage of forest land that is dominated by mixed oaks. Then, by mapping hydrologic units thematically by percentage of oak in their forests, we defined which hydrologic units in the R&V might be best represented by the Leading Ridge BMP experimental results (Figure 3). Based on this approach, the forests of the Leading Ridge experimental site may still be reflective of the majority of the R&V (Figure 3). However, notable exceptions include three hydrologic units that have a greater percentage of oak species than Leading Ridge, two of which are barely within the R&V, and the hydrologic unit at the

FIGURE 1. Point map of the distribution of forest types throughout the Chesapeake Bay watershed. Each point represents a U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) sample point. Forest types are those designated by the USFS FIA. Solid lines represent the boundaries of Bailey's ecoregions (Bailey 1995).

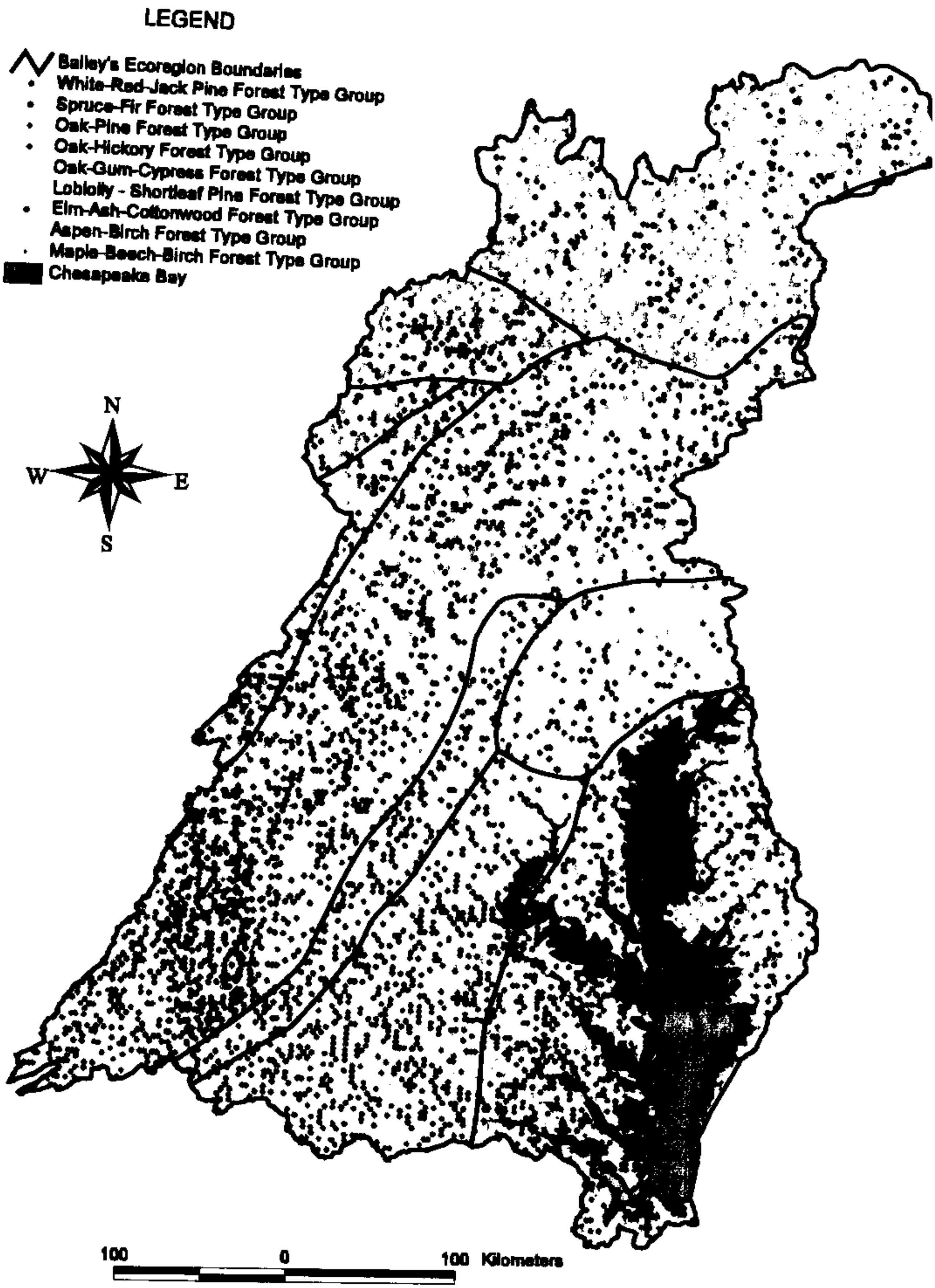

LEGEND
Bailey's Ecoregion Boundaries
White-Red-Jack Pine Forest Type Group
Spruce-Fir Forest Type Group
Oak-Pine Forest Type Group
Oak-Hickory Forest Type Group
Oak-Gum-Cypress Forest Type Group
Loblolly - Shortleaf Pine Forest Type Group
Elm-Ash-Cottonwood Forest Type Group
Aspen-Birch Forest Type Group
Maple-Beech-Birch Forest Type Group
Chesapeake Bay
N
W
E
S
100
0
100 Kilometers

FIGURE 2. Bailey's (1995) ecoregions that occur within the Chesapeake Bay watershed. Each ecoregion is color-coded by the U.S. Forest Service's Forest Inventory and Analysis sample points. The Ridge and Valley physiographic province is comprised of the Northern Ridge and Valley and Blue Ridge Mountains ecoregions. The Piedmont province is subdivided into the Northern Appalachian Piedmont and Southern Appalachian Piedmont ecoregions.

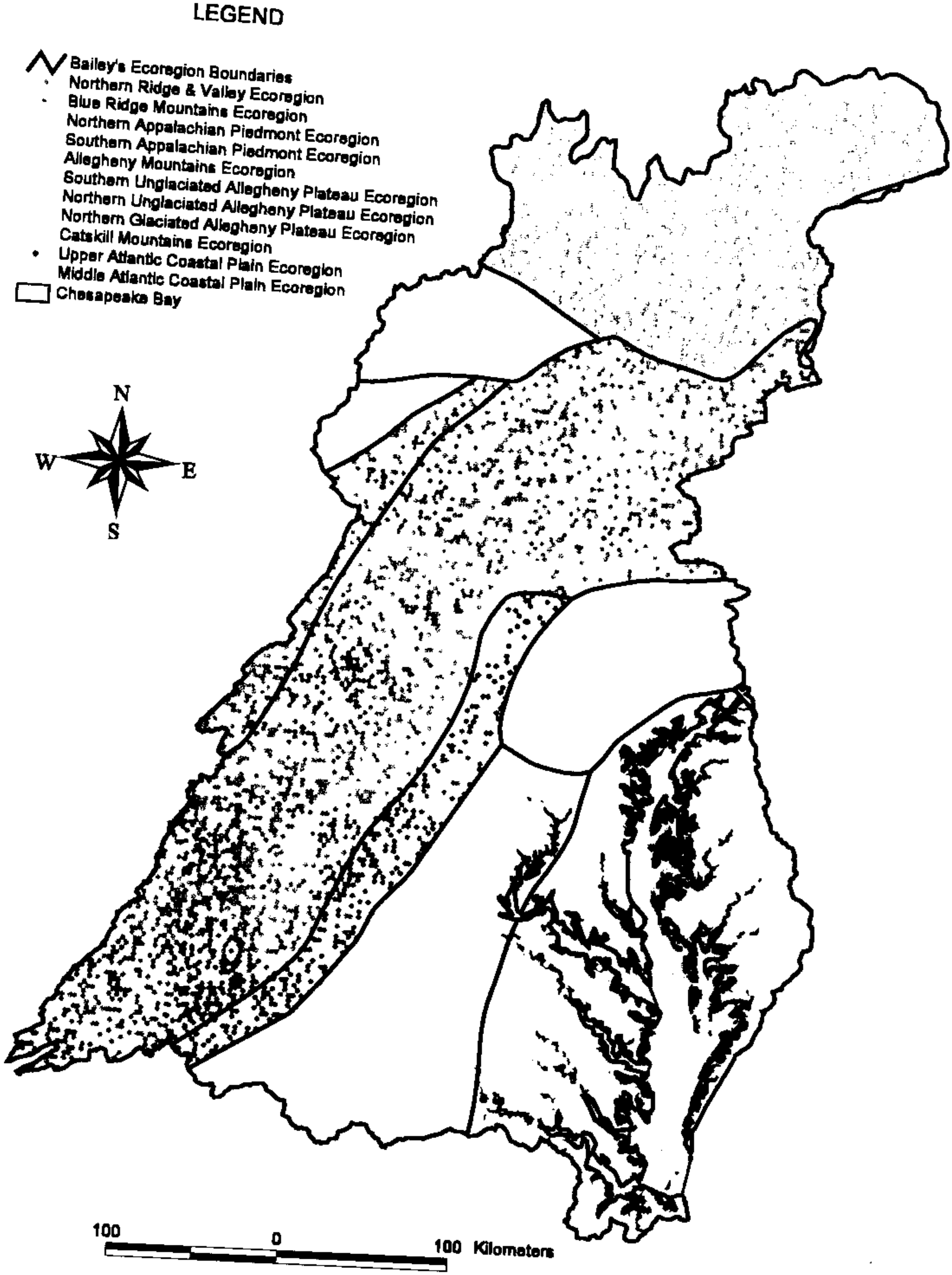
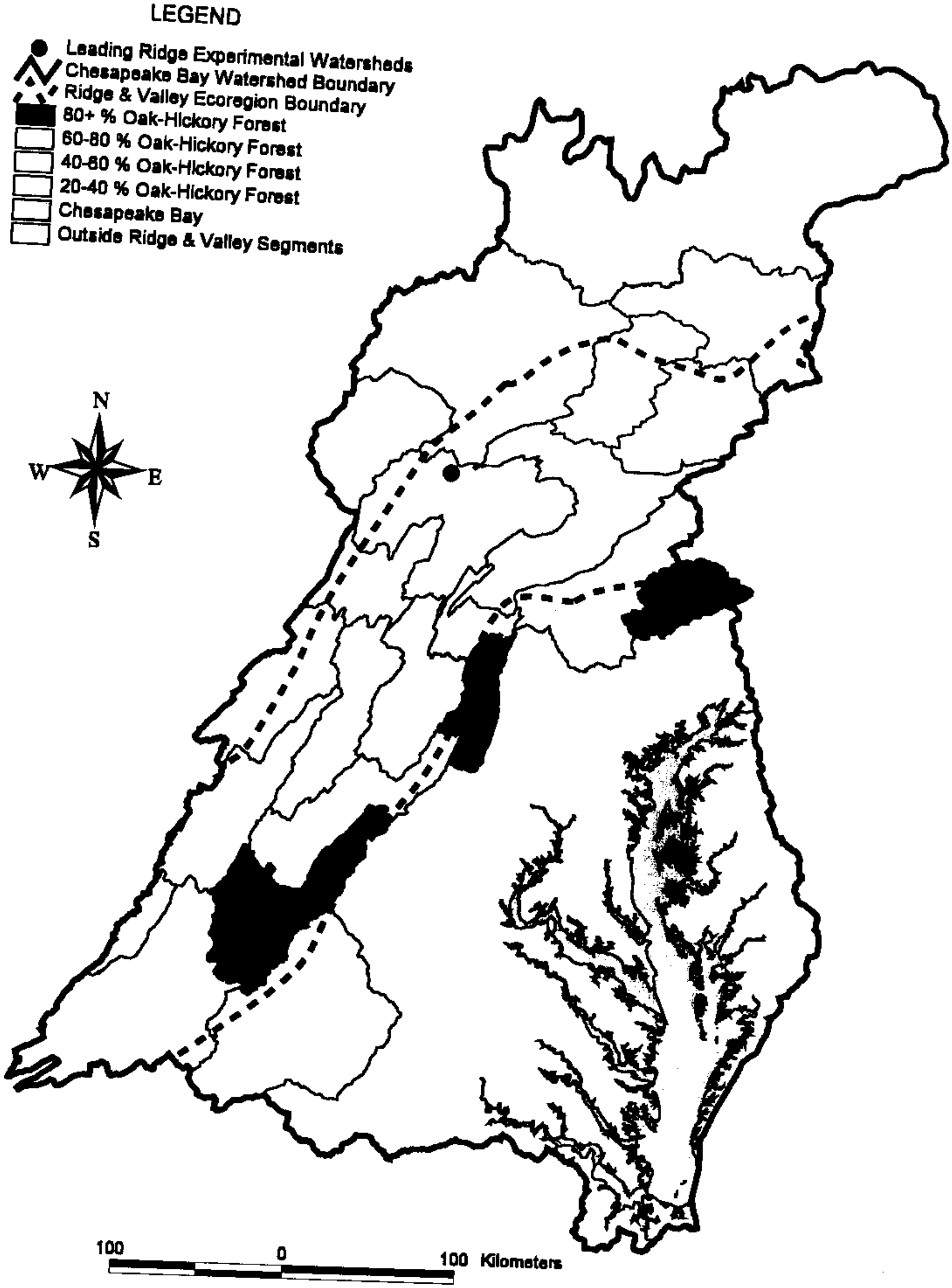

LEGEND
Bailey's Ecoregion Boundaries
Northern Ridge & Valley Ecoregion
Blue Ridge Mountains Ecoregion
Northern Appalachian Piedmont Ecoregion
Southern Appalachian Piedmont Ecoregion
Allegheny Mountains Ecoregion
Southern Unglaciated Allegheny Plateau Ecoregion
Northern Unglaciated Allegheny Plateau Ecoregion
Northern Glaciated Allegheny Plateau Ecoregion
Catskill Mountains Ecoregion
Upper Atlantic Coastal Plain Ecoregion
Middle Atlantic Coastal Plain Ecoregion
Chesapeake Bay
N
W
E
S
100
0
100 Kilometers

FIGURE 3. Percentages of total forest land that is of the oak-hickory forest type within hydrologic units in the Ridge and Valley physiographic province of the Chesapeake Bay watershed. The Ridge and Valley is designated by the dashed lines. Hydrologic units correspond to hydrologic "segments" in the U.S. Environmental Protection Agency's Chesapeake Bay watershed model. Only those segments at least partially within the Ridge and Valley are shown. The location of the Leading Ridge Experimental Watersheds in the north-central Ridge and Valley is indicated by the black dot.


LEGEND
Leading Ridge Experimental Watersheds
Chesapeake Bay Watershed Boundary
Ridge & Valley Ecoregion Boundary
80+ % Oak-Hickory Forest
60-80 % Oak-Hickory Forest
40-60 % Oak-Hickory Forest
20-40 % Oak-Hickory Forest
Chesapeake Bay
Outside Ridge & Valley Segments
N
W
E
S
100
0
100 Kilometers

northern end of the R&V where the oak-hickory forests of the R&V grade into the northern hardwoods of the Northern Glaciated Allegheny Plateau ecoregion (Figures 1, 2, and 3). We feel that this and other more advanced spatial analyses of biological and physical resource distributions in relation to points of BMP experimentation hold promise for (1) more sophisticated extrapolation of BMP function over heterogenous regions, (2) identification of subregions or subwatersheds of special concern for BMP implementation, and (3) greater technical detail on which to base forest nutrient processes and BMP effectiveness in models of the CBW.

Spatial extrapolation of BMP applicability is obviously dependent on a network of experimental studies of BMP effectiveness, with nodes in the network representing logical physical/biological units such as ecoregions. This situation does not currently exist for the CBW. We recommend development of this research/demonstration BMP network with nodes in each ecoregion. Further analyses of spatial variation in geology, soils, and forests within each ecoregion may well indicate the importance of more than one project within the larger ecoregions of the CBW. Development of this network seems superfluous for some BMPs. For example, using sound road construction techniques to avoid erosion is based on physical principles that largely transcend ecoregions. On the other hand, effects of various other BMPs may be much more localized, such as proper management of site preparation, width and construction of SMZs needed for nutrient filtering, and species management within SMZs. BMPs designed to alleviate nutrient runoff, especially SMZs, may be particularly susceptible to nitrogen saturation of vegetation (Aber et al. 1989, Hanson et al. 1994) in those regions of the CBW having high rates of nitrogen deposition. Finally, the focus on control of non-point source nutrient pollution within the CBW dictates greater accuracy in estimating spatial distributions of sources and sinks for non-point source nutrients. Forests and their management are not the primary source for non-point nutrient pollution in the CBW (Donigian et al. 1994, Shulyer 1995) but, by comprising some 60% of the CBW land use and playing a key role in filtering nutrients from other land uses, proper forest management is an important part of the solution.

CONCLUSIONS AND RECOMMENDATIONS

Our comparison of forestry BMP recommendations among the states with land area in the CBW is not meant to be judgmental. It is difficult for anyone not directly involved in the process of developing a BMP manual for the varied topography and forest types of any Bay state to completely understand the complexity of the process. We do hope that our comparison will serve two purposes. First, BMP manuals are probably always in a state of development to concisely cover the multitude of potential topics in a format accessible to the public. Hopefully our comparison will facilitate further development by allowing a direct comparison of BMP practices across states that have at least one similar goal, that being to preserve water quality within the CBW. Secondly, this comparison has identified two areas in which we feel further effort should be placed: definition and protection of intermittent and ephemeral streams, and better protection for wetlands outside of SMZs.

Defining and protecting water courses are high priorities for maintaining high water quality. But significant variation exists among the Bay states in the methods used to define streams that should be protected and the BMPs recommended as protective measures. As stated previously, Maryland's definition of perennial and intermittent streams by "blue lines" or "dashed blue lines" on a 7.5-minute quadrangle maps is precise. However, we question whether this definition is broad enough, particularly because this definition is linked to determining what streams require SMZs or buffers. Other states either poorly define intermittent streams or do not define them at all. The case for ephemeral streams is even more vague and protection from disturbance is afforded them only in West Virginia and possibly New York. We feel that evidence of flowing water, such as having a defined channel and banks, is a conservative and reasonable definition for both intermittent and ephemeral streams. Whether this would be a fair definition raises multiple questions: How much timber would become unavailable for harvest if SMZs were required for all water courses defined in this way? How would the cost of timber harvesting increase if engineered crossings were required for all water courses defined in this way? Can this definition be fairly applied to all landowners? What gain will be made in water quality compared to economic costs associated with this definition? These questions remain unanswered and in need of quantification. Nonetheless, the experimental results of Lynch and Corbett (1990) clearly indicated the potential for intermittent water courses to become significant sources of sediment under the physical conditions created by forest harvesting. In addition, we hypothesize that the microtopography of intermittent and ephemeral water courses promotes high biological activity in the soil and potential accumulation of organic and inorganic nitrogen that will be flushed to perennial stream channels during seasonal or storm-related flows. The costs and benefits of water course definition and protection clearly need further investigation.

All of the Bay states recommend SMZs around designated water courses. These buffers afford general protection to wetlands that are contained within them, although timber harvesting is allowed within SMZs in all Bay states. Our interpretation of recommended BMPs indicates that protection of nontidal wetlands that are not within SMZs is much less stringent for all of the Bay states. This lack of protection applies most specifically to skid trails and log landings. As a positive point, Pennsylvania notably singles out both forested (spring seeps and vernal ponds) and nonforested (marshes) wetlands as areas needing buffer protection. Maryland, Virginia, and Delaware all recommend SMZs for forested wetlands in general. Alternatively, it is unclear what protection (other than federal wetland laws) is afforded nonforested wetlands occurring within harvestable forest tracts in Virginia, West Virginia, and Delaware. As in the case of water courses for buffering, further clarification of definitions, costs, and benefits is warranted.

The two components of BMP compliance are the actual assessment of compliance rates and the rate of compliance itself. As a group, compliance assessment by the Bay states is probably similar to the national percentage of states carrying out such assessments. Because compliance assessment is needed to gauge the public outreach effectiveness of state BMP programs, all Bay states should be carrying out such assessments annually. These assessments should provide for significant and statistically valid sampling designs and sample sizes, and ranking of the degree of compliance for specific BMPs at each harvest site. The compliance reports of Maryland and Virginia clearly indicate the positive impacts of compliance monitoring. Both states have been able to identify specific BMPs that are unacceptable in their compliance rates, as well as those geographic regions where these rates are low. This data is crucial for reassessing public information efforts. The Maryland compliance report (Koehn and Grizzel 1995) is both recent and the first in the state, so feedback from the assessment to field implementation of BMPs cannot be addressed. In comparison, compliance has been monitored in Virginia since 1989. Austin (1995) credits this regular compliance monitoring with identification of problem areas and an increase in compliance of 14.5% from 1989 to 1993. Ice (1989) suggested that measuring BMP compliance is more cost effective than actually monitoring water quality. Superficially, we agree with this statement, but also feel that it is premature for compliance rates to serve as a surrogate of direct water quality monitoring. We base this statement on (1) inconsistencies of BMP recommendations among states, (2) the voluntary nature of compliance in most states, and (3) the sparseness of data quantifying the water quality impacts of recommended BMPs. In particular, we feel it quite feasible that severe degradation of water quality (especially by sediment) can accrue from a small number of poorly managed sites, even in the midst of high overall compliance rates.

It is clearly appropriate to state that forestry BMPs improve the quality of water draining from sites of forest operations and are thus qualitatively effective. The specific effectiveness of BMPs, measured as a percent reduction in sediment or nitrate export, is not well-quantified. We surmise that this lack of quantification stems from the difficulty in performing experiments that require large areas of land and long-term efforts. Stringent empirical tests of BMP effectiveness for protecting water quality need (1) a control watershed, (2) a treatment (e.g. harvested) watershed without BMP implementation, and (3) a treatment watershed in which BMPs are employed. In addition, multiple-year pre-treatment data on water quality for all study watersheds to control for variation accruing from site differences, and multiple-year post-treatment data to account for effectiveness under extreme weather events and long-term sufficiency of treatments are desirable. Even this experimental design can be criticized as statistically incomplete unless control and treatment watersheds are replicated. With the exception of the work by Hornbeck and Reinhart (1964) at FEF all of the studies that we have reviewed lack a "loggers choice" treatment against which to gauge well-planned and managed watershed manipulations and measure the specific effectiveness of BMPs. This specific effectiveness is an important parameter in debating (1) whether BMPs should be regulatory or voluntary, (2) what levels of nutrient flux from forest management activities are controllable versus uncontrollable, (3) cost-benefit analyses of BMP programs and enforcement, and (4) how to assign "fair share" reductions in nutrient loads to meet environmental or policy goals for surface or ground water quality. Thus although the literature we have reviewed provides a strong case for BMP implementation, it also limits both the scope of our conclusions and water quality planning efforts locally and regionally.

After reviewing the impacts of forest management on water quality and BMP effectiveness, Binkley and Brown (1993a) stated that use of "...a certain set of BMP's in one location does not guarantee that those BMP's will be effective in a different location. The soils and their slopes, weather patterns, and several other factors must be considered in the selection of the most effective site-specific BMP's." As we have noted, such a cautionary note is certainly applicable to a geologically and vegetatively diverse area like the CBW. Nonetheless, top-down approaches that subdivide physiographic provinces and ecoregions into smaller units that are hydrogeologically, climatologically, and biologically more homogeneous can provide a template for applying BMPs known to be effective under specific conditions. These techniques would also be applicable to identifying where the BMP experiments, now lacking, should be performed.

It is important to note that most experiments testing BMPs in the eastern United States have been based on small paired watersheds. The relatively high experimental control under such circumstances is important. However, application of forestry BMPs will seldom focus on small catchments, but on patches of forest imbedded in multiple-use landscapes. Such a context introduces new questions to forestry BMP applications. For example, is the width of an SMZ defined by forestry BMPs sufficient when intensive agriculture is located upslope from the harvest site? To address this large-scale context, forestry BMPs will need to be integrated into landscape and regional modeling efforts (e.g. Levine et al. 1993) that explicitly account for spatial patterns of land uses in relation to water flow paths. This integration places forest management and forestry BMPs in the context of cumulative effects (Reid 1993) and moves the study of forestry BMPs from managing on-site effects to cumulative effects both on-site and off-site (Binkley and MacDonald (1994).

Our review has focused on the two primary aspects of forestry BMP effectiveness: reduction of water quality impacts, and compliance. Within the CBW, neither is easily assessed. Lack of direct information on specific effectiveness of BMPs and compliance reporting by only two states combine to prevent quantitative assessments of BMP effectiveness. On a qualitative basis, we estimate that forestry BMPs are providing an invaluable ecological service to the Chesapeake Bay. The value of this service, however, can only be completely assessed by considering forest management in the landscape and regional context of cumulative effects.

ACKNOWLEDGMENTS

We extend our appreciation to the following individuals who assisted us in accessing the BMP information for their respective states: Mr. Rob Northrop - Maryland Department of Natural Resources Forest Service; Mr. Sam Austin and Mr. Mike Foreman - Virginia Department of Forestry; Mr. Kirk Westfall - Delaware Department of Agriculture Forest Service; Mr. Michael Urban - New York Department of Environmental Conservation, Bureau of Forest Resources; Mr Bob Merrill and Mr. Dan Devlin - Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry; Mr. Philip Wygal - West Virginia Division of Forestry. For acquisition of FIA data we are indebted to Mr. Joe Glover USDA Forest Service's Southeastern Forest Experiment Station, and Mr. Tom Frieswyk and Ms. Carol Alerich of the USDA Forest Service's Northeastern Forest Experiment Station. Mr. Bob Webster and Mr. Phil Pannill, of the Maryland Department of Natural Resources Forest Service, provided valuable reviews of the Maryland BMPs. Mr. Al Todd provided multiple helpful comments on an earlier draft of this manuscript. This is AL Publication No. 2869.

REFERENCES

Aber, J. D., K. J. Nadelhoffer, P. Steudler, and J. M. Melillo. 1989. Nitrogen saturation in northern forest ecosystems. *BioScience* 39: 378-86.

Alerich, C. L. 1992. *Forest statistics for Pennsylvania -- 1978 and 1989*, Research Bulletin NE-126. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Alerich, C. L. and D. A. Drake. 1995. *Forest statistics for New York, 1993*, Research Bulletin NE-132. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Askew, G. R., and T. M. Williams. 1986. Water quality changes due to site conversion in coastal South Carolina. *Southern Journal of Applied Forestry* 10: 134-36.

Aubertin, G. M., and J. H. Patric. 1974. Water quality after clearcutting a small watershed in West Virginia. *Journal of Environmental Quality* 3(3): 243-49.

Austin, S. H. 1995. *The Virginia Department of Forestry Water Quality Program: a technical summary*. Charlottesville, VA: Virginia Department of Forestry.

Bailey, R. G. 1995. *Descriptions of the ecoregions of the United States* (Second Edition). Miscellaneous Publication 1391. USDA Forest Service, Washington, DC.

Beasley, R. S. 1979. Intensive site preparation and sediment losses on steep watersheds in the Gulf Coastal Plain. *Soil Science Society of America Journal* 43(2): 412-17.

Binkley, D., and T. C. Brown. 1993a. Forest practices as nonpoint sources of pollution in North America. *Water Resources Bulletin* 29(5): 729-40.

———. 1993b. *Management impacts on water quality of forests and rangelands*, General Technical Report RM-239. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Binkley, D. A. and L. MacDonald. 1994. *Forests as nonpoint sources of pollution, and effectiveness of best management practices*. NCASI Technical Bulletin No. 672. National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

Binkley, D. A., D. Richter, M. B. David, and B. Caldwell. 1992. Soil chemistry in a loblolly/longleaf pine forest with interval burning. *Ecological Applications* 2: 157-64.

Bormann, F. H., G. E. Likens, D. W. Fisher, and R. S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest ecosystem. *Science* 159: 882-84.

Bormann, F. H., G. E. Likens, T. G. Siccama, R. S. Pierce, and J. S. Eaton. 1974. The effect of deforestation on ecosystem export and steady-state condition at Hubbard Brook. *Ecological Monographs* 44: 255-77.

Bureau of Land and Water Conservation, Pennsylvania Department of Environmental Resources and Cooperative Extension, College of Agriculture, Pennsylvania State University. 1992. *Controlling erosion and sedimentation from timber harvesting operations*. The Pennsylvania State University, University Park, PA.

Bureau of Water Quality Management, Division of Water, New York State Department of Environmental Conservation. 1993. *Silviculture management practices catalogue for nonpoint source pollution prevention and water quality protection in New York State*. Albany, NY.

Chesapeake Bay Program. 1994. *Achieving the Chesapeake Bay nutrient goals: a synthesis of tributary strategies for the Bay's ten watersheds*. USEPA, Washington, DC.

Chescheir, G. M., J. W. Gilliam, R. W. Skaggs, R. G. Broadhead, and R. Lea. 1987. *The hydrology and pollutant removal effectiveness of wetland buffer areas receiving pumped agricultural drainage water*. Report No. 231. Water Resources Research Institute of the University of North Carolina, Raleigh.

Comerford, N., R. Mansell, and D. Neary. 1992. *The effectiveness of buffer strips for ameliorating offsite transport of sediment, nutrients, and pesticides from silvicultural operations*, National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

Cooksey, R. A., and A. H. Todd. 1996. *Conserving the forests of the Chesapeake: the status, trends, and importance of forests for the Bay's sustainable future*, NA-TP-03-96. USDA Forest Service, Northeastern Area.

Cooper, S. R. 1995. Chesapeake Bay Watershed historical land use: impact on water quality and diatom communities. *Ecological Applications* 5: 703-23.

Corbett, E. S., J. A. Lynch, and W. E. Sopper. 1975. Forest-management practices as related to nutrient leaching and water quality. In *Non-point sources of water pollution*, pages 157-73. Virginia Polytechnic Institute and State University: Virginia Water Resources Research Center.

——. 1978. Timber harvesting practices and water quality in the Eastern United States. *Journal of Forestry* 76(8): 484-88.

DeWalle, D. R., and H. B. Pionke. 1995. Nitrogen export from forest land in the Chesapeake Bay region. In *Toward a sustainable watershed: the Chesapeake experiment. Proceedings of the 1994 Chesapeake Research* Conference. P. Hill, and S. Nelson, eds. Pages 649-55.

DiGiovanni, D. M. 1990. *Forest statistics for West Virginia -- 1975 and 1989*. Resource Bulletin NE-114. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Dobson, J. E. and E. A. Bright. 1995. *Coastal change analysis program (C-Cap): Chesapeake Bay prototype for wetlands and uplands*. NOAA Technical Memorandum. US Department of Commerce, National Oceanic and Atmospheric Administration.

Donigian, A. S., B. R. Bicknell, A. S. Patwardhan, L. C. Linker, C.-H. Chang, and R. Reynolds. 1994. *Watershed model application to calculate nutrient loadings: final findings and recommendations. Phase II. Nutrient and sediment loads to the Chesapeake Bay: existing conditions scenario*. USEPA, Chesapeake Bay Program Office, Annapolis, MD.

Douglass, J. L. 1975. Southeastern forests and the problem of non-point sources of water pollution. In *Non-point sources of water pollution*, P. M. Ashton and R. C. Underwood, ed., pages 29-44. Blacksburg, VA: Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University.

Douglass, J. E., and D. H. Van Lear. 1983. Prescribed burning and water quality of ephemeral streams in the Piedmont of South Carolina. *Forest Science* 29(1): 181-89.

Ellefson, P. V., and A. S. Cheng. 1995. *Western states nonpoint source program review*, NCASI Technical Bulletin No. 706. National Council of the Paper Industry for Air and Stream Improvement, Inc., Research Triangle Park, NC.

Ellefson, P., and A. Cheng. 1996. *North central states nonpoint source program review*, NCASI Technical Bulletin No. 710. National Council of the Paper Industry for Air and Stream Improvement, Inc., Research Triangle Park, NC.

Environmental Systems Research Institute, Inc. 1994. *PC ARC/INFO version 3.4.2* [DOS-based computer software]. Redlands, CA.

Fisher, D. C. and M. Oppenheimer. 1991. Atmospheric nitrogen deposition and the Chesapeake Bay estuary. *Ambio* 20: 102-108.

Forest Resources and Utilization Branch, Virginia Department of Forestry. 1994. *Best management practice implementation and effectiveness, 1993*. Charlottesville, VA: Virginia Department of Forestry.

Forest Resources and Utilization Branch, Virginia Department of Forestry. 1995. *Best management practice implementation and effectiveness, 1994*. Charlottesville, VA: Virginia Department of Forestry.

Forest Service, Delaware Department of Agriculture. 1995. *Delaware's forestry best management practices manual*. Dover, DE.

Forested Wetlands Task Force, Forest Issues Working Group. 1993. *Best management practices for silvicultural activities in Pennsylvania's forest wetlands: a pocket guide for foresters, loggers, and other forest land managers*. [Publisher and place of publication not listed.]

Fox, T. R., J. A. Burger, R. E. Kreh, and J. E. Douglass. 1983. An overview of watershed and nutrient cycling research at the Reynolds Homestead Research Center. In *Proceedings of the second biennial southern silvicultural research conference*, E. P. Jones Jr., ed., pages 468-76. General Technical Report SE-24, Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Frieswyk, T. and D. M. DiGiovanni. 1988a. *Forest statistics for Delaware -- 1972 and 1986*. Resource Bulletin NE-109. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Frieswyk, T. and D. M. DiGiovanni. 1988b. *Forest statistics for Maryland -- 1976 and 1986*. Resource Bulletin NE-107. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Gardner, R. H., M. S. Castro, R. P. Morgan, and S. W. Seagle. 1996. *Perspectives on Chesapeake Bay: nitrogen dynamics in forested lands of the Chesapeake Basin*, CRC Publication No. 151. Chesapeake Research Consortium, Inc., Edgewater, MD.

Groffman, P. M., A. J. Gold, and R. C. Simmons. 1992. Nitrate dynamics in riparian forests: microbial studies. *Journal of Environmental Quality* 21: 666-71.

Hansen, M. H., T. Frieswyk, J. F. Glover, and J. F. Kelly. 1992. *The Eastwide forest inventory data base: users manual*. General Technical Report NC-151. USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Hanson, G. C., P. M. Groffman, and A. J. Gold. 1994. Symptoms of nitrogen saturation in a riparian wetland. *Ecological Applications* 4(4): 750-756.

Hewlett, J. D. 1979. *Forest water quality: an experiment in harvesting and regenerating Piedmont forest*, School of Forest Resources, University of Georgia, Athens, GA.

Hewlett, J. D., H. E. Post, and R. Doss. 1984. Effect of clear-cut silviculture on dissolved ion export and water quality yield in the Piedmont. *Water Resources Research* 20(7): 1030-1038.

Hibbert, A. R. 1966. Forest treatment effects on water yield. In *International symposium on forest hydrology: proceedings of a National Science Foundation Advanced Science Seminar*, pages 527-43. New York, NY: Pergamon Press.

Hornbeck, J. W., C. W. Martin, R. S. Pierce, F. H. Bormann, G. E. Likens, and J. S. Eaton. 1986b. Clearcutting northern hardwoods: effects on hydrologic and nutrient ion budgets. *Forest Science* 32(3): 667-86.

——. 1987. *The northern hardwood forest ecosystem: ten years of recovery from clearcutting*, Research Paper NE-596. USDA Forest Service, Northeastern Forest Experiment Station, Broomall, PA.

Hornbeck, J. W., C. W. Martin, and C. T. Smith. 1986a. Protecting forest streams during whole-tree harvesting. *Northern Journal of Applied Forestry* 3: 97-100.

Hornbeck, J. W., and K. G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. *Journal of Soil and Water Conservation* 19(1): 23-27.

Hornbeck, J. W., C. T. Smith, C. W. Martin, L. M. Tritton, and R. S. Pierce. 1990. Effects of intensive harvesting on nutrient capitals of three forest types in New England. *Forest Ecology and Management* 30: 55-64.

Hornbeck, J. W., and S. J. Ursic. 1979. Intensive harvest and forest streams: are they compatible? In *Impact of intensive harvesting on forest nutrient cycling*, pages 249-62. Broomall, PA: USDA Forest Service, Northeast Forest Experiment Station.

Howard, R. J., and J. A. Allen. 1989. Streamside habitats in southern forested wetlands: their role and implications for management. In *Proceedings of the Symposium on the Forested Wetlands of the Southeast?*, D. D. Hook and R. Lea, eds., pages 97-106. General Technical Report SE-50, Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Hunsaker, C. T., C. T. Garten, and P. J. Mulholland. 1995. *Nitrogen outputs from forested watersheds in the Chesapeake Bay drainage*, ORNL-ESD Publication Number 4275. Oak Ridge National Laboratory, Oak Ridge, TN.

Johnson, D. W., and D. E. Todd. 1987. Nutrient export by leaching and whole-tree harvesting in a loblolly pine and mixed oak forest. *Plant and Soil* 102: 99-109

Johnson, D. W., D. C. West, D. E. Todd, and L. K. Mann. 1982. Effects of sawlog vs. whole-tree harvesting on the nitrogen, phosphorus, potassium, and calcium budgets of an upland mixed oak forest. *Soil Science Society of America Journal* 46: 1304-9.

Johnson, T. G. 1992. *Forest statistics for Virginia, 1992.* Resource Bulletin SE-131. USDA Forest Service, Southeastern Forest Experiment Station, Asheville, NC.

Karr, J. R. and I. J. Schlosser. 1977. *Impact of nearstream vegetation and stream morphology on water quality and stream biota.* EPA-600/3-77-097. USEPA Environmental Research Laboratory, Office of Research and Development, Athens, GA.

Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201: 229-34.

Kemp, G. P. and J. W. Day. 1984. Nutrient dynamics in a Louisiana swamp receiving agricultural runoff. In *Cypress Swamps*, K. C. Ewel and H. T. Odum, eds., pages 286-93. Gainsville, FL: University of Florida Press.

Kochenderfer, J. N. 1977. Area in skidroads, truck roads, and landings in the Central Appalachians. *Journal of Forestry* 75:507-508.

Kochenderfer, J. N., and G. M. Aubertin. 1975. Effects of management practices on water quality and quantity: Fernow Experimental Forest, W. Virginia. In *Municipal Watershed Management Symposium Proceedings*, pages 14-24. General Technical Report NE-13, Upper Darby, PA: USDA Forest Service, Northeastern Forest Experiment Station.

Kochenderfer, J. N., and P. J. Edwards. 1991. Effectiveness of three streamside management practices in the Central Appalachians. In: *Proceedings of the Sixth Biennial Southern Silvicultural Research Conference*, S. G. Coleman and D. G. Neary, ed., pages 688-700. Asheville, NC: US Forest Service, Southeastern Forest Experiment Station.

Kochenderfer, J. N., and J. D. Helvey. 1984. Some effects of forest harvesting on water quality: Fernow Experimental Forest, West Virginia. In *Proceedings, forest management & water quality conference*.

Koehn, S. W. and G. D. Grizzel. 1995. *Forestry best management practices: managing to save the Bay; an assessment and analysis report on forestry BMP implementation in Maryland.* Annapolis, MD: Maryland Department of Natural Resources, Forest Service.

Kuenzler, E. J. 1989. Value of forested wetlands as filters for sediments and nutrients. In *Proceedings of the symposium: the forested wetlands of the southern United States*, D. D. Hook and R. Lea, eds., pages 85-96. General Technical Report SE-50, Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Levine, D., C.T. Hunsaker, S.P. Timmins and J.J. Beauchamp. 1993. A geographic information system approach to modeling nutrient and sediment transport. Oak Ridge National Laboratory, Environmental Sciences Division Pub. 3996.

Likens, G. E., F. H. Bormann, N. M. Johnson, D. W. Fisher, and R. S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monographs* 40: 23-47.

Linker, L. C., G. E. Stigall, C. H. Chang, and A. S. Donigian. 1994. The Chesapeake Bay watershed model. In *Watershed model application to calculate Bay nutrient loadings: final findings and recommendations*, Donigian, A. S., B. R. Bicknell, A. S. Patwardhan, L. C. Linker, C.-H. Chang, and R. Reynolds, pages ii-x. USEPA, Chesapeake Bay Program Office, Annapolis, MD.

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. 1995. *Water quality functions of riparian forest buffer systems in the Chesapeake Bay watershed*, EPA 903-R-95-004. US EPA, Chesapeake Bay Program Office, Annapolis, MD.

Lowrance, R., R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. *BioScience* 34(6): 374-77.

Lynch, J. A., and E. S. Corbett. 1989. "Effectiveness of BMP's in controlling nonpoint pollution from silvicultural operations." *Proceedings of the symposium on headwaters hydrology*, W. W. Woessner and D. F. Potts, eds. American Water Resources Association, Bethesda, MD.

———. 1990. Evaluation of best management practices for controlling nonpoint pollution from silvicultural operations. *Water Resources Bulletin* 26: 41-52.

Lynch, J. A., E. S. Corbett, and K. Mussallem. 1985. Best management practices for controlling nonpoint-source pollution on forested watersheds. *Journal of Soil and Water Conservation* 40(1): 164-67.

Lynch, J. A., W. E. Sopper, E. S. Corbett, and D. W. Aurand. 1975. Effects of management practices on water quality and quantity: the Penn State Experimental Watersheds. In *Municipal Watershed Management Symposium Proceedings*, pages 32-46. General Technical Report NE-13, Upper Darby, PA: USDA Forest Service, Northeastern Forest Experiment Station.

Mann, L. K., D. W. Johnson, D. C. West, D. W. Cole, J. W. Hornbeck, C. W. Martin, H. Riekerk, C. T. Smith, W. T. Swank, L. M. Tritton, and D. H. Van Lear. 1988. Effects of whole-tree and stem-only clearcutting on postharvest hydrologic losses, nutrient capital, and regrowth. *Forest Science* 34(2): 412-28.

Marion, D. A., and S. J. Ursic. 1993. Sediment production in forests of the Coastal Plain, Piedmont, and Interior Highlands. In *Proceedings: technical workshop on sediments*, pages 19-27. Washington, DC: Terrene Institute.

Marks, P. L., and F. H. Bormann. 1972. Revegetation following forest cutting mechanisms for return to steady-state nutrient cycling. *Science* 176: 914-15.

Martin, C. W., and J. W. Hornbeck. 1994. Logging in New England need not cause sedimentation of streams. *Northern Journal of Applied Forestry* 11(1): 17-23.

Martin, C. W., D. S. Noel, and C. A. Federer. 1984. Effects of forest clearcutting in New England on stream chemistry. *Journal of Environmental Quality* 13(2): 204-10.

Martin, C. W., and R. S. Pierce. 1980. Clearcutting patterns affect nitrate and calcium in streams of New Hampshire. *Journal of Forestry* 78(5): 268-72.

Martin, C. W., R. S. Pierce, G. E. Likens, and F. H. Bormann. 1986. *Clearcutting affects stream chemistry in the White Mountains of New Hampshire*, Research Paper NE-579. USDA Forest Service, Northeastern Forest Experiment Station.

McClurkin, D. C., P. D. Duffy, S. J. Ursic, and N. S. Nelson. 1985. Water quality effects of clearcutting Upper Coastal Plain loblolly pine plantations. *Journal of Environmental Quality* 14(3): 329-32.

Melillo, J. M. 1981. In *Terrestrial nitrogen cycles: processes, ecosystem strategies and management impacts.* F. E. Clark, and T. Rosswall, eds. Pages 427-42. Stockholm: Ecological Bulletins.

Mussallem, K. E., and J. A. Lynch. 1980. Controlling nonpoint pollution from commercial clearcuts. In *Watershed Management*, C. W. Johnson, ed., pages 669-81. New York, NY: American Society of Civil Engineers.

NCRI Chesapeake. 1982. *Major land resource areas in the Chesapeake Bay Watershed: aerial data from the 1982 USDA/SCS National Resource Inventory.* National Center for Resource Innovations. Rosslyn, VA.

Neary, D. G., N. B. Comerford, and L. W. Swift Jr. 1993. Land and riparian interactions with sediment in the Southern United States. In *Proceedings: technical workshop on sediments*, pages 51-60. Washington, DC: Terrene Institute.

New York State Department of Environmental Conservation. 1996. *Timber harvesting guidelines: what are they?* Albany, NY. [2 page brochure]

Osborne, L. L. and D. A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology* 29(2): 243-58.

Patric, J. H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality* 9(1): 73-80.

Patric, J. H., J. O. Evans, and J. D. Helvey. 1984. Summary of sediment yield data from forested land in the United States. *Journal of Forestry* 82(2): 101-4.

Personal Bibliographic Software, Inc. 1995. *Procite 3.1 for Windows, version 3.1*[a DOS-based computer software]. Anne Arbor, MI.

Peterjohn, W. T., and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* 65:1466-75.

Pierce, R. S., C. W. Martin, C. C. Reeves, G. E. Likens, and F. H. Bormann. 1972. Nutrient loss from clearcuttings in New Hampshire. In *Watersheds in transition*, S. C. Csallany, T. G. McLaughlin, and W. D. Striffler, eds., pages 285-95. Urbana, IL: AWRA.

Public Lands Forestry Programs, Maryland Department of Natural Resources. 1992. *Maryland's guide to forest harvest operations and best management practices*. Annapolis, MD.

Reinhart, K. G. 1964. Effect of a commercial clearcutting in West Virginia on overland flow and storm runoff. *Journal of Forestry* 62: 162-73.

Richter, D. D., C. W. Ralston, and W. R. Harms. 1982. Prescribed fire: effects on water quality and forest nutrient cycling. *Science* 215: 661-63.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. *Water Resources Bulletin* 19(1): 73-79.

Riekerk, H., D. G. Neary, and W. T. Swank. 1989. The magnitude of upland silvicultural nonpoint source pollution in the south. In *Proceedings of the symposium: The forested wetlands of the Southern United States*, D. D. Hook and R. Lea, eds., pages 8-18. General Technical Report SE-50, Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station.

Salminen E. M. and R. L. Beschta. 1991. *Phosphorus and forest streams: the effects of environmental conditions and management activities*. Department of Forest Engineering, Oregon State University, Corvallis, OR.

Schmidt, M. F. Jr. 1993. *Maryland's Geology*. Centreville, MD: Tidewater Publishers.

Shulyer, L. R. 1995. *Cost analysis for nonpoint source control strategies in the Chesapeake basin*. Technology Transfer Report EPA 903-R-95-0005. USEPA Chesapeake Bay Program, Annapolis, MD.

Seagle, S. W., R. Pagnotta and F.G. Cross. IN PRESS. *The Chesapeake Bay and northern Adriatic Sea drainage basins: land-use and outputs of nutrients and pollutants.*. American Geophysical Union.

Shepard, J. P. 1994. Effects of forest management on surface water quality in wetland forests. *Wetlands* 14(1): 18-26.

Sopper, W. E. 1975. Effects of timber harvesting and related management practices on water quality in forested watersheds. *Journal of Environmental Quality* 4(1): 24-29.

Spurr, S. H. and B. V. Barnes. 1980. *Forest Ecology: third edition*. New York, NY: John Wiley & Sons.

Stone, R. L., W. T. Swank, and J. W. Hornbeck. 1978. Impacts of timber management and regeneration systems on stream flow and soils in the Eastern Deciduous Forest. In *Forest soils and land use: proceedings of the fifth North American forest soils conference.*, C. T. Youngberg, ed., pages 516-34. Fort Collins, CO: Colorado State University.

Swank, W. T. 1986. Biological control of solute losses from forest ecosystems. In *Solute Processes*, S. T. Trudgill, ed., pages 85-139. New York, NY: Springer-Verlag.

Swank, W. T. 1988. Stream chemistry responses to disturbance. In *Forest hydrology and ecology at Coweeta; Ecological Studies, Vol. 66.* W. T. Swank and D. A Crossley Jr., pages 339-57. New York, NY: Springer-Verlag.

Swank, W. T., and J. T. Waide. 1988. Characterization of baseline precipitation and stream chemistry and nutrient budgets for control watersheds. In *Forest hydrology and ecology at Coweeta.* W. T. Swank, and D. A. Crossley, Jr., eds. Pages 339-57. New York: Springer-Verlag.

Swank, W. T., J. B. Waide, D. A. Crossley, Jr., and R. L. Todd. 1981. Insect defoliation enhances nitrate export from forest ecosystems. *Oecologia* 51: 297-99.

Swift, L. W. Jr. 1984. Soil losses from roadbeds and cut and fill slopes in the southern Appalachian Mountains. *Southern Journal of Applied Forestry* 8(4): 209-15.

———. 1986. Filter strip widths for forest roads in the Southern Appalachians. *Southern Journal of Applied Forestry* 10(1): 27-34.

Trimble, G. R. Jr., and R. S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of Forestry* 55(5): 339-41.

Ursic, S. J. 1986. Sediment and forestry practices in the south. In *Proceedings of the fourth federal interagency sedimentation conference; Volume I*, pages 2-28 to 2-37. Washington, DC: U.S. Government Printing Office.

Ursic, S. J., and J. E. Douglass. 1978. The effects of forestry practices on water resources. In *The W. Kelly Mosley Environmental Forum Proceedings*, pages 33-49. Auburn, AL: Auburn University Press.

Van Lear, D. H., J. E. Douglass, S. K. Cox, and M. K. Augspurger. 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina Piedmont. *Journal of Environmental Quality* 14(2): 169-74.

Virginia Department of Forestry. 1995. *Best management practice implementation and effectiveness - 1994.* Forest resources and utilization branch. Charlottesville, VA.

Virginia Department of Forestry. 1996. *Forestry best management practices for water quality in Virginia: technical guide.* Charlottesville, VA.

Vitousek, P. M., and P. A. Matson.1984. Mechanisms of nitrogen retention in forest ecosystems: a field experiment. *Science* 225: 51-52.

———. 1985. Disturbance, nitrogen availability, and nitrogen losses in an intensively managed loblolly pine plantation. *Ecology* 66: 1360-1376.

Vitousek, P. M., and J. M. Melillo. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. *Forest Science* 25(4): 605-619.

Waide, J. 1994. *Southern regional review of state nonpoint source control programs and best management practices for forest management operations*, NCASI Technical Bulletin No. 686. National Council of the Paper Industry for Air and Stream Improvement, Inc., New York, NY.

Webb, J. R., B. J. Cosby, K. N. Eshleman, and J. N. Galloway. 1995. Change in the acid-base status of an Appalachian mountain catchment following forest defoliation by the gypsy moth. *Water, Air, and Soil Pollution* 85: 535-40.

Weitzman, S., and G. R. Trimble Jr. 1952. Skid-road erosion can be reduced. *Journal of Soil and Water Conservation* 7(3): 122-24.

West Virginia Division of Forestry. 1996. *Best management practice guidelines for controlling soil erosion and water siltation from logging operations in West Virginia.* WVDOF-TR-96-3. Charleston, WV.

Yarbro, L. A., E. J. Kuenzler, P. L. Mulholland, and R. P. Sniffen. 1984. Effects of stream channelization on exports of nitrogen and phosphorus from North Carolina Coastal Plain watersheds. *Environmental Management* 8: 151-60.

Yoho, N. S. 1980. Forest management and sediment production in the South - a review. *Southern Journal of Applied Forestry* 4(1): 27-36.

APPENDIX A. **Summary of forestry best management practice guidelines recommended for Delaware.**

BMP Requirement Status	Voluntary
Government Agency Notification Requirement for Logging Operations	None
Professional Assistance Requirements To Implement BMP	None
Logger Training/Certification Requirements	None
Streamside Management Zone (SMZ) potentially includes:	
Perennial ("Blue Line") streams	Yes
Intermittent ("Dashed Blue Line") streams	Yes - Well-defined stream channels only
Ephemeral streams	No
Open Water	Yes
Nontidal Wetlands	Road construction limitations only
Smallest Minimum / Largest Minimum SMZ Width (ft) for the following disturbances:	
Equipment Operation	0
Roads	50/100 (250 ft. max. nontidal wetlands)
Skid Trails	50 / 100
Landings	100 / 150
Humus disturbance	25 ft. "no harvest zone" (surrounding perennial streams only)
Timber Removal	50 / 100
Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:	
0 - 10 %	50 ft.(expand to 100 ft for "highly erodible soils")
11 -20 %	75 ft.(expand to 100 ft for "highly erodible soils")
21 - 45 %	100 ft.

(Continued)

Streamside Management Zone Restrictions	
Equipment Operation	Limit use by carefully planned skid trail locations, cable and winch, etc.
Roads	No roads in SMZ (except for roads approved for stream crossing)
Skid trails	"Well-planned skid trail locations" recommended
Landings	Locate on well-drained areas a minimum of 50 ft. outside SMZ
Humus Disturbance	Original litter layer should not be disturbed to expose mineral soil
Timber Removal	Must retain 60% of overstory or 60 sq. ft. of basal area evenly distributed throughout buffer zone; a "no-harvest" zone is recommended for the first 25 ft. surrounding perennial streams.
Wetlands Restrictions	
Equipment Operation	None, per se
Roads	To extent covered by federal statutes, and no closer than 50 ft. to main channel or open water (except for purpose of crossing a main channel). Road fills constructed parallel to the flow of main channel and no closer than 200 ft. from the 50 ft. SMZ along main channel, except when road is built for crossing a main channel.
Skid Trail	Locate outside of SMZ
Landings	Locate log decks outside identified wetlands whenever possible
Humus Disturbance	Leave forest floor "essentially undisturbed" within SMZ but no protections specified outside of SMZ
Timber Removal	None, per se; protection consideration provided to extent that wetlands border streamside and open water areas (i.e., subsumed under SMZ)

(Continued)

APPENDIX A. (Continued)

Vegetative Soil Stabilization Schedule	Areas of soil disturbance on slopes >30% must be seeded and mulched within 7 days of disturbance; after logging, bare soil areas with grades >10% and/or areas with erosion potential should be revegetated as the season permits.
Stream Crossings Requirements	Access roads cross SMZs and stream channels at or near a right angle. Water control and drainage structures recommended for roads and skid trails crossing SMZ.
Landings	Guidelines provided for locating, constructing, and managing areas where logs are collected.
Roads/Skid Trails	
Road Design Criteria	Guidelines provided for water control structures and procedures
Cut/Fill Limitations	Vertical road bank cuts should not exceed 5 ft. in height. Roads requiring higher banks should be used only when no alternative is feasible, and should be sloped to a least a 2:1ratio and seeded.
Grade Limitation	Roads should be <10% grade; steeper gradients (>15%) permissible for distances of 200 ft. or less. Skid trails should be <15% and parallel to slope except to avail boundary lines, sensitive areas, or other areas not accessible using lesser grades.
Ruts - max. dimension	Should not exceed, on average, 6 in. deep over a distance of 50 ft.; unavoidable rutting of greater than 18 in. deep should be repaired when possible.

(Continued)

Soil Erodibility Considerations	Highly erodible (>7% slope) soils that are disturbed must be seeded and mulched. Restrict traffic over highly erodible soils when soils are saturated.
Chemical Use Limitations	No chemical pesticide or fertilizer use in SMZ.

Source: Forest Service, Delaware Department of Agriculture. 1995. Delaware's forestry best management practices manual. Dover, DE.

APPENDIX B. ***Summary of forestry*** **best management practice guidelines recommended for Maryland (above Fall Line)**

BMP Requirement Status	Regulatory
Government Agency Notification Requirement for Logging Operations	MD Department of Environment or county sediment control agency notified 48 hr. before operation begins
Professional Assistance Requirements To Implement BMPs	Required for operations that disturb a specified buffer zone around streams and open water; disturbances planned for streamside buffer zone require assistance of a licensed forester
Logger Training/Certification Requirements	Required training in erosion/sediment control
Streamside Management Zone (SMZ) Potentially Includes:	
Perennial ("Blue Line") streams	Yes
Intermittent ("Dashed Blue Line") streams	Yes
Ephemeral streams	No
Open Water	Yes
Nontidal Wetlands	Only portions that also contain open water or stream, or are identified on USGS 7.5 minute maps as "lakes, ponds, bogs or marshes"
Smallest Minimum / Largest Minimum SMZ Width (ft.) for the Following Disturbances:	
Equipment Operation	50 w/ buffer mgmt. plan; 50 / 250 without plan
Roads	50 / 250 (except those approved for stream crossings)
Skid Trails	50 / 250
Landings	50 / 250 required; 100 / 300 recommended

(Continued)

Humus Disturbance	50 / 250 (forest floor should be "essentially undisturbed" to maintain an unbroken organic litter layer and prevent exposure of mineral soil)
Timber Removal	Partial cutting allowed throughout SMZ with professional forester's plan, but minimum of 60% crown cover or 60 sq. ft. / ac. basal area should be evenly retained; clearcutting not allowed
Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:	
0 %	50 ft.
1 - 10 %	75 ft.
11 - 20 %	100 ft.
21 - 30 %	150 ft.
31 - 40 %	200 ft.
41 - 50 %	250 ft.
Streamside Management Zone Restrictions	
Equipment Operation	None within 50 ft. of stream or open water; Otherwise "limit the use of logging equipment" (plan designed by a licensed forester required for disturbance in SMZ)
Roads & Skid Trails	Locate outside of SMZ except where not practicable (plan designed by a licensed forester required for disturbance in SMZ)
Landings	Locate outside SMZ (50 ft. recommended)
Soil Disturbance	Humus layer cannot be disturbed within 50 ft. of stream or open water, and should be "essentially undisturbed" elsewhere in SMZ (plan designed by a licensed forester required for disturbance in SMZ)
Timber Removal	Must retain 60% crown cover or 60 sq. ft. / ac. of basal area evenly throughout buffer zone (plan by licensed forester required for SMZ disturbance)

(Continued)

Wetlands Restrictions	
Equipment Operation	None
Road	Only allowed to the extent covered by federal statutes, and no closer than 250 ft. to main channel or open water
Skid Trails	Located outside of SMZ
Landings	Locate in uplands or "higher elevation islands within large wetland sties"
Humus Disturbance	Minimal to no disturbance allowed within SMZ; no restrictions outside SMZ
Timber Removal	None; protection provided to the extent that wetlands border streamside and open water areas (i.e., subsumed under Buffer Zone)
Vegetative Soil Stabilization Schedule	Disturbed areas on slopes >30% must be seeded and mulched within 7 days of disturbance; After logging operation, bare soil with grades >10% and/or areas with erosion potential should be revegetated as the season permits
Stream Crossings Requirements	Temporary stream crossing permit needed from MD Dept. of Environment. to cross perennial or intermittent streams draining 400 ac. or more (100 ac. or more if trout waters)
Landings	Detailed guidelines provided for locating, constructing, and managing
Roads/Skid Trails	
Road Design Criteria	Guidelines provided for various water control structures and procedures
Cut/Fill Limitations	>3 ft. requires Soil Conservation District (SCD) approval in E. MD; >5 ft. requires SCD approval in W. MD mountain counties

(Continued)

Grade Limitation	>15% requires SCD approval; In W. MD skid trails may be 15-20% for up to 200 ft., >20% requires SCD approval
Ruts - max. dimension	Not over 6" deep on average over 50 ft.
Soil Erodibility Considerations	None
Chemical Use Limitations	None

Source: Public Lands Forestry Programs, Maryland Department of Natural Resources. 1992. Maryland's guide to forest harvest operations and best management practices. Annapolis, MD. [Note: Regulations and BMPs for timber operations within the Chesapeake Bay Critical Area are not covered by this report.]

APPENDIX C. Summary of forestry best management practice guidelines recommended for New York.

BMP Requirement Status	Voluntary
Government Agency Notification Requirement for Logging Operations	None
Professional Assistance Requirements To Implement BMPs	None
Logger Training/Certification Requirements	None
Streamside Management Zone (SMZ) Potentially Includes:	
Perennial streams	Yes
Intermittent streams	Only when "flowing" (if not flowing, recommended not to use streambed for skidding)
Ephemeral streams	Not specifically identified, but possibly protected when "flowing"
Open Water	Yes, ponds and lakes
Nontidal Wetlands	Only "marshes" afforded special consideration
Smallest Minimum / Largest Minimum SMZ Width (ft.) for the Following Disturbances:	
Equipment Operation	0
Roads	100 ft. / 150 ft.
Skid Trails	50 ft. / 150 ft.
Landings	200 ft.
Humus Disturbance	None
Timber Removal	10 ft. no-cut zone recommended for all logging operations; 50 ft. no-cut zone recommended within clearcuts
Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:	
0 - 10 %	50 ft. setback for skid trails and 100 ft. setback for roads
11 - 30 %	100 ft. setback for skid trails and roads
> 30 %	150 ft. setback for skid trails and roads

(Continued)

Streamside Management Zone Restrictions	
Equipment Operation	None
Roads	Not within minimums of 100/150 ft
Skid Trials	Not within minimums of 100/150 ft.
Landings	Set back at least 200 ft. from streams, ponds, lakes and marshes
Humus Disturbance	None
Timber Removal	If clearcutting, leave 50 ft.-wide uncut strips along both sides of ponds, marshes and flowing streams; if partial cutting, avoid cutting trees and destroying understory within 10 ft. of stream bank
Wetlands Restrictions	
Equipment Operation	None
Roads	None
Skid Trails	None
Landings	Set back at least 200 ft. from open/flowing waters or marsh
Humus Disturbance	None
Timber Removal	None
Vegetative Soil Stabilization Schedule	Seedings established immediately after logging activities cease"; mulch should be applied at a rate of about 2 tons of hay or straw per acre
Stream Crossings Requirements	Permits required from DEC for crossing "classified" streams; use temporary culverts, bridges or runways where stream bottoms or banks might be damaged; temporary crossings should be removed within 14 days of the crossing's last use; clear guidelines are listed for road construction/drainage requirements
Landings	Recommend placement "on gently sloping ground that drains well"; 200 ft. setback from streams, ponds, lakes and marshes

(Continued)

Roads/Skid Trails	
Road Design Criteria	Roads and trails should be kept "out of wet and poorly drained spots, and off the tops and toes of banks and slopes"; water diversion structures recommended for "roads and primary skid trails when slopes exceed 10%"
Cut/Fill Limitations	Should be "minimized"
Grade Limitation	Grades 10% or less for road construction, and 15% or less for "primary skid trails"
Ruts - max. dimension	None
Soil Erodibility Considerations	None
Chemical Use Limitations	Follow federal, state, and local rules and regulations for use of hazardous materials (e.g., pesticides, fertilizers, petroleum products, road salt, etc.)

Sources: Bureau of Water Quality Management, Division of Water, New York State Department of Environmental Conservation. 1993. Silviculture management practices catalogue for nonpoint source pollution prevention and water quality protection in New York State. Albany, NY.

New York State Department of Environmental Conservation. 1996. Timber harvesting guidelines: what are they? Albany, NY. [2 page brochure]

APPENDIX D. Summary of forestry best management practice guidelines recommended for Pennsylvania

BMP Requirement Status	Voluntary
Government Agency Notification Requirement for Logging Operations	None
Professional Assistance Requirements To Implement BMPs	Site-specific sediment control "plan must be prepared by person trained and experienced in erosion and sedimentation control methods" for each timber harvesting operation; plan "must be available at the site during the entire period of harvesting operations."
Logger Training/Certification Requirements	None
Stream Management Zone (SMZ) Potentially Includes:	
Perennial Streams	Yes
Intermittent Streams	Yes, if watercourse has "a channel or conveyance of surface water having defined banks, whether natural or manmade, with perennial or intermittent flow"
Ephemeral Streams	Special protection only for "spring seeps"; Unclear if these "intermittent" watercourses have "defined banks"
Open Water	None
Nontidal Wetlands	No-cut buffers of 10 ft. around temporary ("vernal") pond banks and spring seeps; retain 50% canopy cover in balance of 50 ft. buffer around seep. No skidding through vernal ponds/seeps; soil disturbance should be avoided around these features; and logs should be winched out of 50 ft. buffer zone rather than enter the pond or seep buffer with

(Continued)

	equipment. Avoid making ruts deeper than 6 in. within 200 ft. of a vernal pond. Where property boundaries permit, locate haul roads at least 150 ft. downstream from the head of a seep, and avoid road building within 150 ft uphill from seeps.
Smallest Minimum / Largest Minimum SMZ Width (ft.) for the Following Disturbances:	
Equipment Operation	None (but "concentrate skidding in defined corridors and use cable skidding when possible")
Roads	25/165 ft. (except for roads approved for stream crossings)
Skid Trails	None (see nontidal wetlands under Stream Management Zone - above)
Landings	25/165 feet
Humus Disturbance	None (see nontidal wetlands under Stream Management Zone - above)
Timber Removal	No clearcutting allowed within 50 ft. of streams; should "maintain at 50% crown cover as a residual stand"
Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:	
0 %	25 ft.
1 - 10 %	45 ft.
11 - 20 %	65 ft.
21 - 30 %	85 ft.
31 - 40 %	105 ft.
41 - 50 %	125 ft.
51 - 60 %	145 ft.
61 - 70 %	165 ft.
Streamside Management Zone Restrictions	
Equipment Operation	None

(Continued)

Roads	None allowed within 25 ft. of perennial stream; roads located between 25 and 50 ft. of perennial stream require a water obstruction permit or written waiver from the Bureau of Dams and Waterway Mgmt.
Skid Trails	None
Landings	Same as Roads
Humus Disturbance	None
Timber Removal	No clearcutting within 50 ft. of streams; "maintain at least 50% crown cover as a residual stand"
Wetland Restrictions	
Equipment Operation	Avoid locating landings in wetlands, unless no other locations are practical
Road/Skid Trail	DER permit required for fill deposition to construct temporary and permanent roads. Permit not required "for the placement of support mats, corduroy and other temporary fabricated roads for use as skid trails" if removed after operation. Avoid equipment use in small wetlands. Skidding confined to a few primary trails to minimize area affected. In larger wetlands requiring skidder entry, schedule harvest in drier seasons or when ground is frozen. Skidding should cease when excessive rutting occurs. Use brush or corduroy to minimize soil compaction and rutting in wet areas. Temporary road crossings of wetlands should be avoided if an alternate location is possible; otherwise, crossing is permissible if located at the narrowest point of the wetland and the length of crossing in the wetland is <200 ft.

(Continued)

Landings	Avoid locating in wetlands; if no other locations are practical, use only in dry season and place "on highest ground possible when in wetland"
Humus Disturbance	None
Timber Removal	None (except for spring seeps and vernal ponds, see SMZ discussion in nontidal wetlands section)
Vegetative Soil Stabilization Schedule	None
Stream Crossings Requirements	State permit required for all crossings of stream channels "having a defined bed and banks...with perennial or intermittent flow of surface water. Fords cannot be used for skidding; stream crossing approaches should not exceed 10% slope within 50 ft. of the crossing
Landings	Guidelines provided for locating, constructing, and managing
Roads/Skid Trails	
Road Design Criteria	Guidelines provided for various water control structures and procedures
Cut/Fill Limitations	None
Grade Limitation	None
Ruts - max. dimension	None
Soil Erodibility Considerations	None
Chemical Use Limitations	None

Sources:

Bureau of Land and Water Conservation, Pennsylvania Department of Environmental Resources and Cooperative Extension, College of Agriculture, Pennsylvania State University. 1992. Controlling erosion and sedimentation from timber harvesting operations. The Pennsylvania State University, University Park, PA.

Forested Wetlands Task Force, Forest Issues Working Group. 1993. Best management practices for silvicultural activities in Pennsylvania's forest wetlands: a pocket guide for foresters, loggers, and other forest land managers. [Publisher and place of publication not listed.]

APPENDIX E. Summary of forestry best management practice guidelines recommended for Virginia

BMP Requirement Status	Voluntary		
Government Agency Notification Requirement for Logging Operations	None		
Professional Assistance Requirement To Implement BMPs	None		
Logger Training/Certification Requirements	None		
Streamside Management Zone (SMZ) Potentially Includes:			
Perennial streams	Yes; defined as solid blue line on the USGS 7.5 minute quadrangle map		
Intermittent streams	Yes; defined as dashed blue line on USGS 7.5 minute quadrangle maps		
Ephemeral streams	Yes; apparently includes all other watercourses that flow "in direct response to precipitation"		
Open Water	Yes		
Nontidal Wetlands	Road construction limitations only		
Smallest Minimum / Largest Minimum SMZ width (in ft.) for the Following Disturbances:			
Equipment Operation	0 ft.		
Roads	50 ft. (up to 125 ft. for trout waters)		
Skid Trails	50 ft. (up to 125 ft. for trout waters)		
Landings	100 ft. (up to 175 ft. for trout waters)		
Humus Disturbance	50 ft. (up to 125 ft. for trout waters)		
Timber Removal	50 ft. (up to 125 ft. for trout waters) for clearcutting; selective cutting is allowed throughout SMZ		
Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:			
	Non-trout	Trout	Municipal Supply
0 - 10 %	50 ft.	66 ft.	100 ft.
11 - 20 %	50 ft.	75 ft.	150 ft.

(Continued)

21 - 45 %	50 ft.	100 ft.	150 ft.
>45 %	50 ft.	125 ft.	200 ft.

Streamside Management Zone Restrictions	
Equipment Operation	"Limit the use of logging equipment; use dispersed skidding, cable & winch, etc."
Roads/Skid Trails	Unacceptable unless necessary to cross stream
Landings	Set back at least 50 ft. outside of SMZ
Humus Disturbance	"Leave the forest floor essentially undisturbed. The organic litter layer should not be broken through to expose mineral soil." All roads, cuts and fills (>=5% slope or subject to erosion) should be stabilized using a seeding mixture "within the first 15 days of next seeding season."
Timber Removal	Partial harvesting acceptable. Minimum 50% crown cover to be evenly retained in the SMZ.
Wetlands Restrictions	
Equipment Operation	"Move equipment to uplands during periods of potential flooding, wet periods, or when rutting exceeds an average depth of 8 inches for 50 lineal feet."
Roads	Truck haul road fills constructed "only when absolutely necessary;" should be constructed parallel to main channel and no closer than 200 ft. from the 50 ft. SMZ, except when the road is built for crossing a main channel."
Skid Trails	None; same as for upland areas
Landings	Locate on upland more than 50 ft. from SMZ for "narrow" wetlands
Humus Disturbance	None
Timber Removal	None

(Continued)

Vegetative Soil Stabilization Schedule	Disturbed areas with a grade of 5% or greater or subject to erosion should be seeded immediately after harvest.
Stream Crossings Requirements	Perennial or intermittent stream crossings must use bridge or culvert of acceptable design
Landings	Locate at least 50 ft. from SMZ
Roads/Skid Trails	
Road Design Criteria	Skid trails located outside of SMZ; logs should not be skidded through intermittent or perennial streams.
Cut/Fill Limitations	"Vertical road bank cuts should normally not exceed 5 ft. in height. When no alternate is feasible, road bank cuts > 5 ft. high should normally be sloped to at least a 2:1 ratio and seeded to prevent erosion.
Grade Limitation	Skid roads limited to <=15% grade; truck haul roads should follow contours with grades 2% - 10%; steeper grades permissible for distances <200 ft.
Ruts - max. dimension	Truck haul road should be reworked to remove ruts when average depth exceeds 6 in. over >50 ft or when off-site damage may occur from hauling operations.
Soil Erodibility Considerations	On soils with severe erosion hazard, truck haul "road grades should be 8% or less, but grades exceeding 12% for 150 ft. may be acceptable as long as measures are taken to prevent erosion."

(Continued)

APPENDIX E. (Continued)

Chemical Use Limitations	Fertilizer should not be broadcast with 50 ft. of "open water or identifiable water courses." Application of pesticides and fertilizers should follow manufacturer's instructions.

Source: Virginia Department of Forestry. 1996. Forestry best management practices for water quality in Virginia: technical guide. Charlottesville, VA.

APPENDIX F. Summary of forestry best management practice guidelines recommended for West Virginia

BMP Requirement Status	Voluntary; Mandatory license requirement, acceptance of which "implies that operator will protect environmental quality through the judicious use of BMPs"
Government Agency Notification Requirement for Logging Operations	Must submit a "timbering operation notification form" to WV Division of Forestry within 3 days of start of logging, and operation must posted operator ID on-site
Professional Assistance Requirements To Implement BMPs	Logging crews must be supervised at least once a day by a "certified logger"; who must have satisfactorily completed the State's safety and BMP course
Logger Training/Certification Requirements	"Certified" loggers are required to attend State-sponsored training "update" course every third year to maintain license
Streamside Management Zone (SMZ) Potentially Includes:	
Perennial streams	Yes (defined as continuously flowing water most years)
Intermittent streams	Yes (defined as having well defined banks and natural channels, but typically flows only part of year)
Ephemeral streams	Yes (defined by flows as a result of wet weather conditions when ground is saturated; channel evident)
Open Water	Yes (undefined extent)
Nontidal Wetlands	No

(Continued)

Slope Correction to Determine Actual Extent of SMZ on Each Side of Watercourse:	Perennial/Intermittent	Ephemeral
0 % average slope to watercourse	100 ft.	25 ft.
>1% average slope to watercourse	100 ft.	25 ft.
Smallest Minimum / Largest Minimum SMZ Width (ft.) for the Following Disturbances:		
Equipment Operation	0; But "should be limited"	
Roads	100 (25 ft. for all ephemeral streams); Should not be located within SMZ except to enter or leave crossings	
Skid Trails	100	
Landings	100; Should be located outside of SMZ "where practical"; 25 ft. width for ephemeral streams.	
Humus disturbance	0; Logging activities should "prevent exposure of mineral soil"; "if mineral soil is exposed it should be stabilized by seeding and mulch as soon as possible"	
Timber Removal	0; Permitted so long as mineral soil is not exposed	
Wetlands Restrictions		
Equipment Operation	None	
Roads	None	
Skid Trails	None	
Landings	"Should be located on dry, firm sites" but no specific guidance for wetlands	
Humus Disturbance	None	
Timber Removal	None	
Vegetative Soil Stabilization Schedule	Upon completion of skidding, "areas subject to erosion should be stabilized quickly." Erosive areas to be seeded and mulched include: all landings, all road fill when road is within filterstrip, 50 ft. on each side of perennial and intermittent stream crossings. Erosive areas that should be seeded include skid roads and trails >15% slope, truck	

(Continued)

	roads >10% slope, all roads or trails within filter strip, roads and trails within 100 ft. of landing.
Stream Crossings Requirements	Streams are to be crossed at a right angle and approaches to stream graveled for 100 ft.; fords are permissible "as a last resort, but only when the stream bottom is rock based and can support truck traffic." Skid roads crossing "live stream" will require a bridge or culvert. Water control structures are required.
Landings	Guidelines provided for locating, constructing, and managing
Roads/Skid Trails	
Road Design Criteria	Guidelines provided for various water control structures/procedures
Cut/Fill Limitations	None
Grade Limitations	Truck haul roads should be 10% or less in grade; Skid roads/trails "should not be steeper than 15% with exception of short, steep segments not exceeding 20%." However, skid roads and trails with "grades up to 40% are acceptable if no mineral soil is exposed."
Ruts - max. dimension	None
Soil Erodibility Considerations	None
Chemical Use Limitations	None

Source: West Virginia Division of Forestry. 1996. Best management practice guidelines for controlling soil erosion and water siltation from logging operations in West Virginia. WVDOF-TR-96-3. Charleston, WV.