8-1996

MR400: Assessing Compliance with BMPs on Harvested Sites in Maine: Final Report

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CFRU Research Bulletin 11

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Miscellaneous Report 400

August 1996

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PREFACE

This research project was conducted by the University of Maine in response to questions raised by the Forestry Advisory Team (FORAT), which is a group that advises the Maine Department of Environmental Protection (DEP) and the Maine Forest Service (MFS) on controlling water pollution from forestry activities. The research was designed to help answer three questions:

- What are the documented types of impacts on water quality from forestry activities in Maine?
- Do timber harvesters use the best management practices recommended by the state to control water pollution?
- Are these practices effective when they are used?

The project was conducted in two parts. First, all literature that documents water quality impacts from forestry in Maine and other similar geographic areas was reviewed in a report published by the Cooperative Forestry Research Unit in June 1996 (CFRU Information Report 38). Second, a field survey was conducted to investigate whether harvesters are using best management practices recommended by the state to control water pollution and whether these practices appear to be effective when they are used. This report presents an analysis of the data collected in the field survey.

Both parts of this research project were funded primarily by the Maine Department of Environmental Protection with a grant from the U.S. Environmental Protection Agency under the Clean Water Act section 104. The costs of the project exceeded the grant, so additional funds were contributed by the Maine Forest Products Council and some staff time donated by the Cooperative Forestry Research Unit.

Forestry Advisory Team Members

Maine Dept. of Conservation, Maine Forest Service—represented by Tom Charles and Peter Baringer

Maine Dept. of Environmental Protection, Bureau of Land and Water Quality—represented by Lew Allen and Tony St. Peter

Land Use Regulation Commission—represented by Will Johnston

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EXECUTIVE SUMMARY

The Society of American Foresters task force report on water quality revealed that silvicultural activities were near the bottom of a list that ranked the contribution of various land use activities to nonpoint source pollution (NPSP) problems affecting surface waters in the U.S. (SAF 1995). Agriculture leads the list, accounting for NPSP problems in 41% of rivers and streams. Although the impacts are small relative to other land uses, forestry activities do have the potential to generate sediment and affect water quality. The literature review that preceded this study (Stafford et al. 1996) showed that forestry best management practices (BMPs) are effective in reducing soil erosion and maintaining the high water quality associated with forested lands. Recognizing the importance of BMPs, this study evaluates the degree of compliance with forestry BMPs in Maine.

This study was undertaken in the spirit of cooperation between the University and landowners of the state, who willingly allowed us access to their land; many took the time to show us their land in person. All of these individuals were interested in sound practices for protection of water quality and long-term site productivity.

A sample of 120 harvested sites, randomly selected from the intent to harvest reports that were filed with the Maine Department of Conservaton for the period January 1, 1993, to December 31, 1994, were selected for a field visit. These sites were evenly distributed among four jurisdictional and geographic strata: organized north, organized south, unorganized east, and unorganized west. Access was refused on only two sites (less than 2% of those sampled); hence, these data should provide an unbiased assessment (at one point in time) of BMP compliance in Maine for the two-year period.

The forestry BMPs were organized into six groups (haul roads, stream crossings, skid roads and trails, putting trails and roads to bed, log yards/landings, and streamside management zones). A field data sheet was designed to facilitate compliance monitoring. At each site, the field visit focused first on potential problem areas (stream crossings, skid trails on steep topography, landings, and haul roads). The site examination radiated outward from potential problem areas so that 30 to 50 acres of the surrounding landscape were visited; two sites were completed during the average 12-hour day.

In order to reduce the temptation to misinterpret the results, it is important to understand how compliance was assessed. The ratings are presented on a site basis. Each BMP was numerically rated for compliance as follows: 1 = gross neglect, 2 = major departure, 3 = minor departure, 4 = meets or exceeds practice. The rating was used as a *qualitative* indication of compliance within an individual site. For example, if among all culverts observed only one exhibited a major departure from the applicable BMP, the site received a rating of 3 (minor departure) for the applicable BMP. However, if half or more of the culverts examined at that site exhibited major departure or gross neglect, the site was rated as 2 or 1, respectively. Compliance was expressed as the number of sites rated 3 or 4 divided by the total number of sites for which the particular BMP was applicable. Effectiveness was assessed by examining evidence for sediment movement (1 = ineffective, significant delivery to surface water, 2 = ineffective, some delivery to surface water, 3 = minor impact, no delivery to surface water, 4 = negligible sediment movement).

Physical Features

Among the four strata, physical site attributes were relatively uniform; there were no differences in the distribution of water features or the distribution of soil drainage.

BMPs

- All of the BMPs were not applicable on all of the sites; the number of applicable sites ranged from 16 (log crossings do not impede water flow) to 120 (minimize the number of roads).
- Those BMPs dealing with planning and location of roads, skid trails, and landings exhibited high levels of compliance (90% and higher). Since the scientific literature documents that 99% of all sedimentation problems originate with haul roads/skid trails, this group of BMPs is the critical initial step for prevention of erosion and sedimentation.
- Compliance was lower for the BMPs dealing with diversion of water from trails, roads, and landings. The objective of this group of BMPs is to break up the long steady slopes where water is concentrated in flow paths, which increase erosive force and undermine road and trail surfaces. More attention should be paid to this group of practices.
- Road systems that were installed decades ago, using procedures that were considered to be acceptable at that time, apparently contribute to sedimentation problems. Those old roads (and some poorly constructed new roads) were constructed by scraping surface soil down to the basal till and piling the material outward into road banks. This method left ditches that redirected water towards the road surface over time because water was prevented from moving away from the road surface by the high banks. Diverting water away from those old road systems requires a great deal of effort and excavation of the old banks.
- BMP compliance was clearly associated with substantial reduction and elimination of both incidence and severity of sediment movement. Regardless of BMP category, noncompliance of individual BMPs resulted in a marked increase in sediment movement and delivery to surface waters. BMPs work very well.
- Considered as a group, the BMPs associated with yards and landings had the highest degree of overall compliance whereas those associated with putting sites to bed had the lowest degree

of compliance.

- BMPs dealing with culvert maintenance and drainage ditch stabilization were not often complied with. More attention must be devoted to these two categories because of the potential for continued generation of sediment.

INTRODUCTION

Maine is rich in renewable natural resources; commercial forest land covers approximately 16.8 million acres (Seymour and Lemin 1991). The forestry sector is a major component of the state economy. Analysis of economic data reported for Maine's forestry sector indicated that the total value of products generated was $5.076 billion in 1990 (Field[1])

Maine has abundant water resources, due to its physical location in the Northeast where precipitation exceeds evapotranspiration and is evenly distributed throughout the year. The numerous streams, ponds, lakes, wetlands, along with the ocean, provide high-quality water, fish habitat, and recreational opportunities. The vitality of Maine's economy is completely dependent on continued maintenance of water quality and forest productivity, both of which are inextricably linked to the soil.

Forest management operations associated with timber harvesting have the potential to disturb soil, leading to erosion. The consequences are both acute (decreased water quality) and chronic (reduced long-term site productivity). Both can be avoided by minimizing soil disturbance. The practices that have been designed to minimize or eliminate soil displacement and transport are collectively referred to as best management practices (BMPs). Most states have developed a set of BMPs for use in forest management. Maine's forestry BMPs are detailed in a Maine Department of Conservation publication (1991).

Interest in assessing the effectiveness of best management practices (BMPs) on maintenance of water quality from managed forests is currently strong, as indicated by the number of reports and literature reviews that have been published in the last few years (Binkley and Brown 1993a, 1993b; NCASI 1992, 1994, 1995, 1996; White and Krause 1993). A joint technical session of the Soils, Water Resources, Silviculture, and Remote Sensing Working Groups of The Society of American Foresters, entitled "BMPs Operational Practices to Insure Sustainability," was conducted at the 1995 national convention in Portland, Maine (Society of American Foresters 1996).

Quantification of the effectiveness of BMPs in reducing soil movement is difficult and expensive. It is virtually impossible to adequately replicate such studies over the complete range of site conditions that exist. Studies that have been done generally show that BMPs are effective in maintaining water quality (Adams and Hook 1993; NCASI 1992). Given acceptance of the hypothesis that BMPs are generally effective in keeping soil in place (consequently protecting both water quality and long-term site productivity) assessment of the degree of compliance is appropriate. Compliance surveys have been done for several states at varying degrees of intensity (Adams 1994; Brynn and Clausen 1991; Carraway and Norris 1996; Rossman and Phillips 1992; Schultz 1992). The Maine Department of Environmental Protection surveyed 23 (of a total of 6115) sites harvested in organized towns during 1993 and estimated that 30% exhibited serious potential for erosion and sedimentation problems (Maine Department of Environmental Protection 1994). The sample was small and statistical reliability was not assessed. In general, the results were similar to those obtained in Minnesota, where a sample of 48 harvested sites indicated an overall compliance rate of 79% (Rossman and Phillips 1992).

One of the few studies designed to obtain results with a high level of statistical precision was reported by Adams (1994) in South Carolina. He estimated that a sample of 177 sites was required to provide an estimate of BMP compliance within ± 5% of the actual value at a 95% confidence level. Compliance levels were estimated overall and in five broad categories (roads, stream crossings, stream management areas, harvests, and log yards/landings). Overall compliance was 85%. Although compliance with road stream crossings was low (42%), only 12 of the 177 sites involved road stream crossings, resulting in a wide confidence interval (10%-70%).

OBJECTIVES

The objectives of this study were to assess the level of BMP compliance in Maine, provide an indication of the statistical precision of these estimates, and to examine BMP effectiveness using evidence of sediment transport as a surrogate. Reliable assessment of BMP compliance will facilitate identification of problem areas that should be targeted by education and training programs.

METHODS

The state was stratified according to state environmental agency jurisdiction into organized (Maine DEP) and unorganized (Maine Land Use Regulation Commission) towns. This stratification was used in order to assess any differential degree of compliance between the unorganized towns, subject to LURC harvesting standards (Maine Land Use Regulation Commission 1991), and the organized towns. The organized towns have no erosion control standards, except for the rules restricting harvesting in protected shoreline zones (extending landward 75 ft from high water mark). In the organized towns, code enforcement officers, already overworked with more immediate problems, have the primary responsibility for enforcement of regulations that apply to protected shoreline zones as

[1]Unpublished report based on Micro-IMPLAN analysis of 1990 data by Dr. David B. Field, Dept. of Forest Management, University of Maine, 10 February 1995.

well as for any additional town codes (which may or may not exist). In order to ensure geographic representation within organized and unorganized towns, those strata were divided geographically as follows: ON, organized north; OS, organized south; UE, unorganized east; and UW, unorganized west.

Based on an estimate of the desired statistical precision and the availability of field time and funding, a sample size of 120 harvested sites (each at least 10 acres in area) was targeted. A variety of problems that could have prevented a field visit (i.e., landowner permission refused, site cannot be located by field crew) were anticipated. In order to ensure an adequate number of sites for sampling, the Maine Forest Service randomly selected 240 sites (evenly distributed among the substrata described above) from intent to harvest forms that were filed with the Maine DOC for the period January 1, 1993, to December 31, 1994. A letter explaining the study and requesting permission to visit the property (accompanied by a brief questionnaire) was mailed to each landowner identified through the site selection process. Positive responses (as well as lack of negative response) were assigned to the pool of potential sites. The owner was invited to be present at the time of the field visit. Thirty of those sites from each of the substrata were subsequently randomly selected for a field visit.

Field work was conducted during the period June through October 1995 by Soil Consulting Services, Monson, ME. Physiographic data were recorded at each site. The BMPs were organized into the following groups: haul roads, skid roads and skid trails, stream crossings, putting trails/roads to bed, log yards/landings, and streamside management zones. Each BMP was rated for its applicability at each site. All BMPs that were applicable were then rated for degree of compliance as follows:

1. Gross neglect of BMP (practice not used),
2. Major departure from BMP (installation so poor that practice is ineffective),
3. Minor departure from BMP (minor imperfections that do not compromise BMP function),
4. Operation meets or exceeds BMP requirement.

This rating system subjectively incorporates both quality of the BMP installation and consistency within each site. In order to clarify this rating system, several examples of minor departures follow; it would be unmanageable to include justifications for every rating recorded.

- Departure from the BMP requiring adequate drainage ditches to divert water away from the road was rated as minor when soils were somewhat excessively drained and there was no evidence of water running in roads;
- Departure from the BMP requiring slash kept out of stream channel was rated as minor when an isolated incidence of slash present in a stream was observed near a sidehill landing;
- Departure from the BMP restricting harvesting of sensitive sites to the period when the ground is frozen was rated as minor when an isolated occurrence of a rutted wet hole was encountered.

There were occasional situations where one or more of the applicable BMPs could not be rated for degree of compliance. One common example is the BMP dealing with culvert depth (one foot below surface). If the culvert was removed after the operation, compliance could not be rated. In general, this situation occurred in fewer than 3% of the sample sites.

Each practice was then rated for evidence of sediment delivery to water using the following scale:

1. Ineffective, evidence of sediment delivery to stream or lake,
2. Minor impact, evidence of sediment delivery to drainage but not to streams/lakes,
3. Negligible sediment movement (less than 5 ft),
4. Effective, no evidence of sediment movement.

Evidence for sediment delivery was judged according to whether the impact appeared to be acute (short-term problem that is, or will be, eliminated in a short time period) or chronic (long-term, continuing sediment delivery). A copy of the data collection form is provided in the Appendix.

Field work focused generally on those areas in the landscape where problems were most likely to occur: at, or in close proximity to, water features or seep areas. However, many acres distant from water features were examined. Consequently, these data do not quantify the degree of BMP compliance within a given site. An attempt was made to provide a qualitative estimate of compliance within a site using the compliance rating itself. For example, a site in which one culvert out of 20 did not comply with the applicable BMPs was rated as a minor departure if it was an isolated problem that was inconsistent with the majority of culverts that were examined. A rating of “major departure” or “gross neglect” was used only if (a) the BMP was consistently violated, i.e., applicable to the majority of situations encountered on the site or (b) there was direct and severe impact to a waterbody (only one case in the entire study).

A team of individuals with representation from the University of Maine, Maine Department of Environmental Protection, Maine State Planning Office, Maine Forest Service, Maine Forest Products Council, USDA Natural Resources Conservation Service, U.S. Environmental Protection Agency, and the Audubon Society joined the field evaluator at the initiation of the project and midway towards completion of the field work to ensure widespread agreement and understanding of the BMP compliance ratings that were used.

Data Analysis

The distributions of size of harvest areas and of soil drainage classes (well, moderately well, somewhat poorly, poorly, and very poorly) were graphically compared among the four strata (organized north, organized south, unorganized east, unorganized west) using Box plots. A contingency table was used to analyze the relationship between water features (perennial, and intermittent streams, lakes/ponds) and the four strata. A chi-square analysis was used to test the null hypothesis that the distribution of water features was independent of strata.

The proportion of sites in compliance with each BMP was calculated (Cunia 1984) for the organized and unorganized towns, and for both strata combined as follows:

[1] $P_c = n_c / n_a$, where
n_c = number of sites with compliance rating of 3 or 4
n_a = total number of sites for which the practice was applicable.

The variance of the proportion was computed as

[2] $S_{pp} = P_c * (1 - P_c) / (n_a - 1)$.

The 95% confidence interval was computed as

[3] $P_c \pm t_{(\alpha/2)}$ SQRT {Spp}

The relatively small sample size within each of the strata makes a rigorous comparison of compliance in organized and unorganized towns impossible. However, it is possible to examine BMPs within a group. The average compliance proportion difference was computed for each of the BMP groups: haul roads (BMPs 1-24, and 32), stream crossings (BMPs 25-31, and 33), skid roads and trails (BMPs 34-37, and 39), putting trails and roads to bed (BMPs 40-47), log yards/landings (BMPs 48-54), and streamside management zones (BMPs 55-61). A t-test was used to test the hypothesis of no difference in the proportion of compliance for the BMP group between organized and unorganized towns. The correlation between BMP compliance and harvest acreage was estimated for each BMP.

RESULTS

Characterization of the Study Sites

The 120 study sites were well distributed both geographically and jurisdictionally across the state (Figure 1). The stratified random sampling utilized had the desired effect. Although surface water features were present at every site, the distribution of those features among the four strata was statistically uniform (Table 1). At least half of the study sites included perennial streams. Lakes and ponds, although less common, were also included. The hypothesis of independence between strata and water features was accepted using the Chi-square test (p=0.957).

Examination of Box plots reveals considerable similarity in soil drainage class distributions (as a percentage of individual sites) among the four strata (Figures 2–6). The vertical box, bound on the bottom and top by the 25^{th} and 75^{th} percentiles, respectively, illustrates the central tendency for the 30 sites in each stratum (29 for organized north, 31 for organized south). The median percentage of area covered by each soil drainage class is denoted by the horizontal line within the vertical box. The range is indicated by the vertical lines, referred to as whiskers, that extend beyond the vertical box. Extreme values (beyond 1.5 times the distance of the central 50%, are denoted by open circles. For example, the median percentage of well drained soils for the 30 sites in the organized northern towns is 20%; half of the sites have a lower percentage and half have a higher percentage of area in well drained soils. Fifty percent of those 30 sites have well drained soils occupying 10%–40% of the area (the vertical span of the box). The area occupied by well drained soils in the organized north ranges from 0% to 65%. For each soil drainage class, the median percentages among the four strata were within 10% of each other.

The reported harvest acreages tended to be smaller in the organized towns relative to the unorganized towns (Table 2). The smallest harvests were located in the organized south, with a median of 30 acres while the largest harvest areas were located in the unorganized east. One site in the organized north was smaller than the 10 acre mini-

Table 1. Distribution of water features across four strata for the 120 sites sampled during the 1995 field season.

Stratum	Perennial Stream	Intermediate Stream	*Ephemeral Stream	Lake or Pond
Organized North	17	15	17	4
Organized South	14	12	23	5
Unorganized West	20	17	23	4
Unorganized East	19	11	19	3

*As used in this study, this term denotes a drainage or flow of water that is not technically considered a "stream" under Maine law.

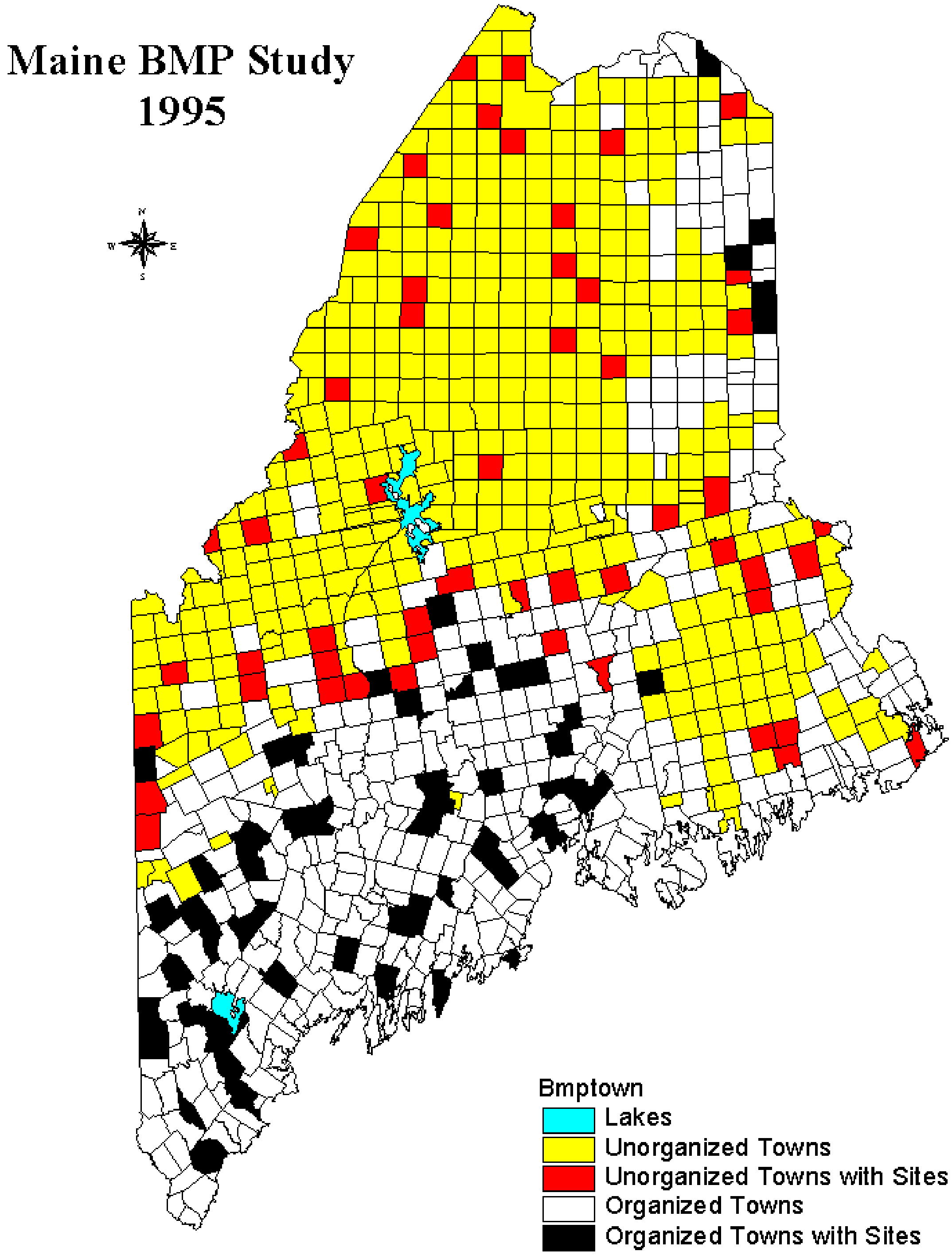


Figure 1. Location of study sites in organized and unorganized towns.

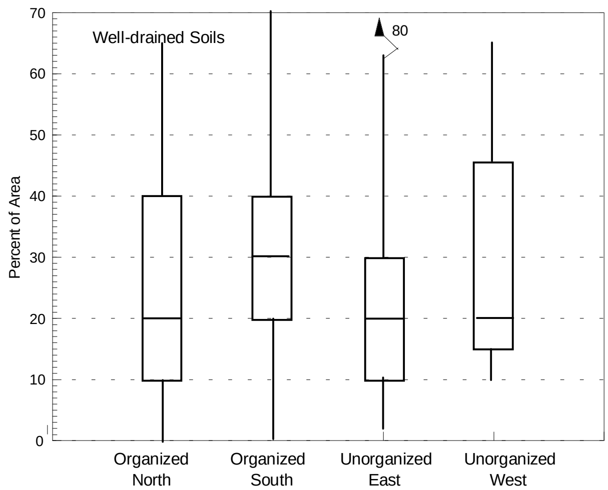


Figure 2. Distribution of the percentage of area in well drained soils across the 120 study sites.

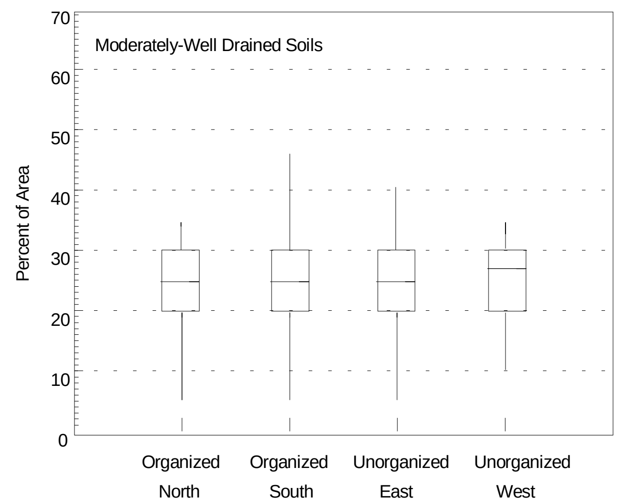


Figure 3. Distribution of the percentage of area in moderately well drained soils across the 120 study sites.

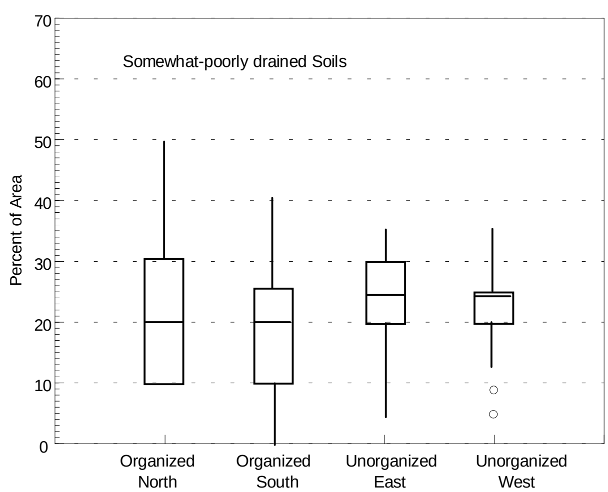


Figure 4. Distribution of the percentage of area in somewhat poorly drained soils across the 120 study sites.

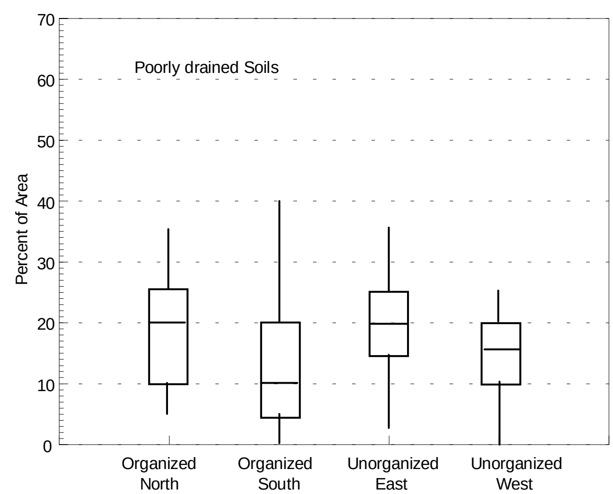


Figure 5. Distribution of the percentage of area in poorly drained soils across the 120 study sites.

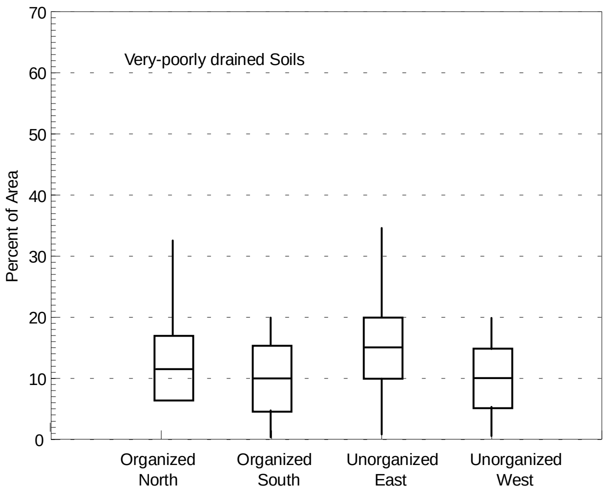


Figure 6. Distribution of the percentage of area in very poorly drained soils across the 120 study sites.

mum, but was reported as 10 acres on the intent to harvest form. The site was kept in the study. The total acreage for a few sites was not reported, consequently the sample size was less than 30 for each stratum. Most of the harvested parcels in the organized townships were owned or managed by small nonindustrial private landowners (NIPF) (Table 3). The large land management and industrial forestry companies were the dominant landowners for the parcels harvested in the unorganized townships, (12% and 17%, respectively), which is consistent with ownership patterns.

BMP Compliance and Effectiveness

Haul Roads—Compliance

The number of study sites for which the haul road BMPs were applicable ranged from 16 to 120 (Table 4). Compliance was computed on the basis of only those sites where the specific practices were applicable.

The percentage of sites in compliance with haul road BMPs ranged from 100% to 34%. The statistical precision was relatively high but decreased with decreasing sample size, a consequence of the fact that not all practices were applicable at all sites. The 95% confidence bounds for those practices that were applicable on at least 90 sites were 10% or less. In contrast, the confidence bound for BMP 14, which deals with angle of culvert installation on slopes greater than 10% gradient, was 22%. That

Table 2. Distribution of area (acres) of harvested study sites by stratum.

Stratum	N	Minimum	1st Quartile	Median	3rd Quartile	Maximum
Organized North	28	4	32	68	115	1400
Organized South	29	10	15	30	50	318
Unorganized West	28	10	40	92	500	6000
Unorganized East	29	10	55	300	1100	2200

Table 3. Distribution of the 120 sampled harvest sites by ownership category.

Ownership Category	Organized North	Organized South	Unorganized West	Unorganized East
NIPF < 1000 ac	26	24	7	10
NIPF > 1000 ac	1	2	5	3
Land Management Company	1	0	3	9
Municipal	0	1	0	0
State	0	1	4	1
Large Industrial	1	0	11	6
Real Estate	0	3	0	0
Blueberry Grower	0	0	0	1
TOTAL	29	31	30	30

Table 4. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for haul road BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
18	100 ± 0	NA	4. Appropriate use of winter roads.
87	98 ± 3	NA	2. Use existing roads unless they aggravate erosion.
120	98 ± 2	NA	1. Minimize number of roads
93	94 ± 5	NA	3. Fit road to topography; avoid wet areas and the toes of slopes (p10).
84	93 ± 6	NA	5. Avoid flat sections that are difficult to drain (p10).
93	92 ± 5	NA	8. Avoid sharp curves (minimum 50' turn radius) (p10).
32	91 ± 10	4.84*	32. Culvert extends beyond any fill (p25).
89	89 ± 7	NA	7. Keep roads 75' from streams, 250' from lakes, great ponds (p10).
92	86 ± 7	NA	6. Keep road grade within 3%-5%, maximum 10% slope (p10).
49	82 ± 11	40.43**	19. Inlet extends into side ditch, intercepting all water (p25).
16	81 ± 22		14. On slopes > 10% install culverts at a 30° angle down slope (p25).
16	81 ± 22	8.34*	22. Broad-based drainage dips discharge area protected using stone, grass, sod, slash, etc. (p14).
50	72 ± 13	18.04**	15. Culverts installed at least 1 ft below surface, and slopes 5 in/10ft (p25).
50	64 ± 13	16.85**	13. Culvert cross sectional area adequate for water flow (usually minimal 15") (p24).
92	55 ± 10	29.27**	10. Drainage ditches adequate to divert water away from the road (p11).
92	53 ± 10	17.57**	20. Roads crowned where possible.
50	52 ± 14	7.24*	18. Outflow length adequate, empties onto stone, slash, or logs, and water prevented from reentering road (p27).
81	47 ± 11	18.45**	21. Broad-based drainage dips used/spaced properly (p13).
82	46 ± 11	45.46**	9. Road banks no steeper than 2:1 (p10).
36	44 ± 16	17.13**	23. Cut/fill banks or other exposed areas outside of road bed within 75' of water vegetated or otherwise stabilized.
36	44 ± 16	11.06**	24. Road grades broken at stream crossings and surface water dispersed to filter strips.
68	41 ± 12	28.26**	12. Cross drainage culverts spaced appropriately (p25).
48	40 ± 14	29.26**	17. Culverts maintained adequately or removed (p25).
49	37 ± 14	20.23**	16. Culvert shoulders stabilized w/stone (p25).
59	34 ± 12	29.42**	11. Drainage ditches stabilized (p11).

[a]Number of harvested sites where BMP was applicable.
[b]Compliance in percent ± 95% confidence bound.
[c]Chi-square statistic (2 df) testing hypothesis of independence of BMP compliance and evidence for sediment movement (none, minor, major); * denotes rejection at $\alpha = 0.05$; ** denotes rejection at $\alpha = 0.01$. Non-significant statistics are not reported; NA denotes not applicable.

practice was appropriate on only 16 of the 120 sample sites.

Arrangement of BMPs by decreasing compliance level facilitates identification of those practices that are routinely followed. The BMPs associated with road layout and location (BMPs 1–8) generally exhibited high levels of compliance (Table 4). Haul roads apparently are well planned. Given the high costs associated with road construction, this finding makes sense.

The BMPs associated with water diversion from road surfaces (culverts, broad based drainage dips) exhibited lower levels of compliance than those associated with road layout and location. Although compliance for two of the water diversion BMPs was in the range of 70%–80% (i.e., culverts installed on slopes in excess of 10% were angled 30°; drainage ditch discharge area protected), compliance with the last 11 was relatively low (34%–55%; Table 4). More effort should be devoted to addressing the latter 11. Compliance for several of those BMPs can be improved easily with little additional cost, simply by paying more attention to detail. It would be a simple matter (except in cases of shallow bedrock) to ensure that culverts are installed at least one foot below the road surface and with the proper slope to allow for water movement. Secondly, it is also a simple matter (albeit more costly) to use the minimum diameter culvert (15 in), as well as to ensure that the outflow empties onto stabilized material (slash, stone, etc.) and does not reenter the drainage ditch. Improving compliance with the cross drainage culvert spacing recommendations is one practice that could add significantly to costs.

The variety of compliance rating systems coupled with differences among states in BMPs that are recommended make comparison of our results with other studies difficult. Nevertheless, limited comparison provides some sense of the degree of similarity and differences among states where compliance monitoring has been undertaken. Our results follow a pattern similar to those reported for several states. Brynn and Clausen (1991), working in Vermont, reported that compliance with acceptable management practices (AMPs, comparable to practices labeled as BMPs) involving planning roads and trails (skid trails not to exceed 20% for more than 300 ft and truck roads not to exceed 10% slope for more than 300 ft) was high (97% and 94%, respectively). However, compliance with those practices dealing with water diversion was low (permanent road dips and culverts 28%, temporary road waterbars 0%, spacing of water bars on skid trails 20%). These general trends reflect our findings in Maine.

Similarity in patterns of BMP compliance are not restricted to the Northeast. Phillips et al. (1994) examined BMP compliance on 261 sites in Minnesota from 1991 to 1993, rating 5,707 individual practices. Departures from recommended practices for water crossings and drainage structures on roads and skid trails were reported 42% of the time; 40% of those were rated as major departures or gross neglect. This group of practices accounted for 15% of the total practices rated, and accounted for 45% of the departures identified. The authors recommended educational emphasis on proper installation of water diversion devices.

Carraway and Norris (1996), based on a sample of 135 harvested sites in Texas, also reported higher compliance for BMPs related to planning of haul roads and skid trails, relative to those practices dealing with water diversion and crossings. Compliance with stream crossing stabilization was only 58% whereas those BMPs dealing with road grade specifications and avoiding sensitive areas had compliance levels of 93% to 95%.

Our observations in the field indicated that one of the more difficult problems encountered is presented by road systems that were constructed decade(s) ago by what was at that time considered to be acceptable practice. Haul roads were constructed by scraping surface soil down to the basal till and piling the material outward. This method leaves a road surface in which ditches migrate laterally towards the road surface as running water erodes the bank near the road over time. Ditches cannot adequately divert water from the road surface (BMP 10) and water now runs down the road. Corrective measures are very expensive because new water diversion ditches, which disturb more of the area, must be excavated through the material that was originally pushed up in banks at roadside. The low compliance with BMP 10 often was due to old road systems.

Road maintenance (or the lack thereof) should be given more attention. Because of the increasing pressures on foresters' time, it is often difficult to return to inactive sites where road systems remain in place. Culverts that become partially obstructed with debris contribute directly to road deterioration as well as generation of sediment that reduces stream water quality. Drainage ditches that are not stabilized with slash or vegetation provide a continual source of sediment to the ditch and potentially to surface water. The tendency for road banks to be steeper than the recommended 2:1 grade compounds this problem.

A common unifying theme among many of the BMPs for which compliance was low is the lack of attention to breaking up the long, uninterrupted stretches of road surface. These long stretches channel water flow, increasing the erosive force, and provide a conduit for delivery of sediment directly to streams. Broad-based drainage dips, crowning of road surfaces, and reversing road gradient (dip) several feet in front of bridge approaches, should be used for the reduction of long, uninterrupted stretches.

Considering all of the haul road practices as a single group without regard to site, overall compliance with those BMPs was 69% in the current study. This figure represents the proportion of individual haul road BMPs rated as either exceeds-meets (4), or minor departure from (3), individual BMPs relative to all of the haul road BMPs across the 120 sample sites.

Haul Roads—Evidence of Sediment Movement

Evidence of sediment movement (or lack thereof) associated with each of the haul road BMPs was tallied by three categories at each site where those practices were applicable (Table 5). The strength of this association was evaluated using a Chi-square statistic to test the hypothesis of independence between compliance and evidence of sediment movement (Table 4). The hypothesis was rejected for all of the BMPs for which it was possible to rate evidence of sediment movement (i.e., the non-planning BMPs in Table 4); many of those rejections were at very low probabilities (below 0.01 and in some cases <0.005) of making a type I error. The generally high level of statistical significance coupled with published criticism that the traditional restriction that 80% or more of expected cell frequencies be greater than 5 is not supported by empirical evidence (Roscoe and Byars 1971). Therefore, this study provides strong statistical evidence that BMP compliance substantially reduces sedimentation. This latter comment applies to all similar tables that follow; consequently it will not be explicity repeated.

Even with BMP compliance, there may be some sediment movement. However, that movement generally is localized and sediment seldom finds a pathway to surface waters when BMPs are followed. There were a few exceptions in which sediment was delivered to streams when BMPs were installed correctly. Drainage ditches were installed (BMP 11) on one site to divert water from steep sections of road. In spite of adequate spacing and construction, water ran down the short road sections between ditches and delivered sediment to a stream. At another site, a culvert initially installed one foot below the road surface (BMP 15) heaved. Water flowed below the culvert resulting in sediment delivery to a stream. It is important to point out that these occurrences, while they provide spectacular contrasts, were isolated exceptions; BMPs are effec-

Table 5. Cross tabulation of haul road BMP compliance[a] vs. evidence of sediment movement[b] on sites where haul road BMPs were applicable.

BMP	Sediment Movement for Compliant Sites			Sediment Movement for Noncompliant Sites		
	None	Minor	Major	None	Minor	Major
32. Culvert extends beyond fill	19	10	0	0	3	0
19. Cross drain inlet	39	1	0	0	5	2
14. Culvert angle	9	4	0	1	0	0
22. Protected discharge area	11	1	1	0	2	1
15. Culvert depth	28	6	2	2	10	0
13. Culvert cross section area	27	5	0	4	11	1
10. Adequate drainage ditch	28	17	6	1	32	8
20. Road crowned	22	18	9	3	31	9
18. Outflow treatment	12	13	1	3	19	0
21. Broad based dips	15	18	5	1	28	14
9. Road banks < 2:1	30	8	0	3	31	10
23. Cut-fill stabilized	10	3	3	1	2	17
24. Road grades broken	7	2	7	0	3	17
12. Cross drain culvert spacing	14	14	0	0	27	11
17. Culverts maintained	17	2	0	2	21	2
16. Culvert shoulder stabilized	11	6	1	1	27	1
11. Drainage ditches stabilized	12	6	2	0	31	8

[a]Compliant sites rated as 3 or 4; noncompliant sites rated as 1 or 2. Totals may be lower than the number of applicable sites (Table 4) because it was not possible to rate sediment movement for culverts that were removed.
[b]Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).

tive in most cases. Noncompliance, in contrast, is clearly associated with increases in both incidence and severity of sediment movement (Figure 7).

For noncompliant sites, there is a noticeable shift from the majority of sites in the category "none" to the categories of "minor" and "major," which more often characterize the noncompliant sites. This trend is visually apparent in Figure 7, which presents the percentage of sites rated for sediment movement (none, minor, major) within each of compliant and noncompliant site groups. The single exception is for BMP 14 (culvert angled properly). This result is an aberration due to the small sample size for noncompliant sites; there was no sediment movement in the single noncompliant site.

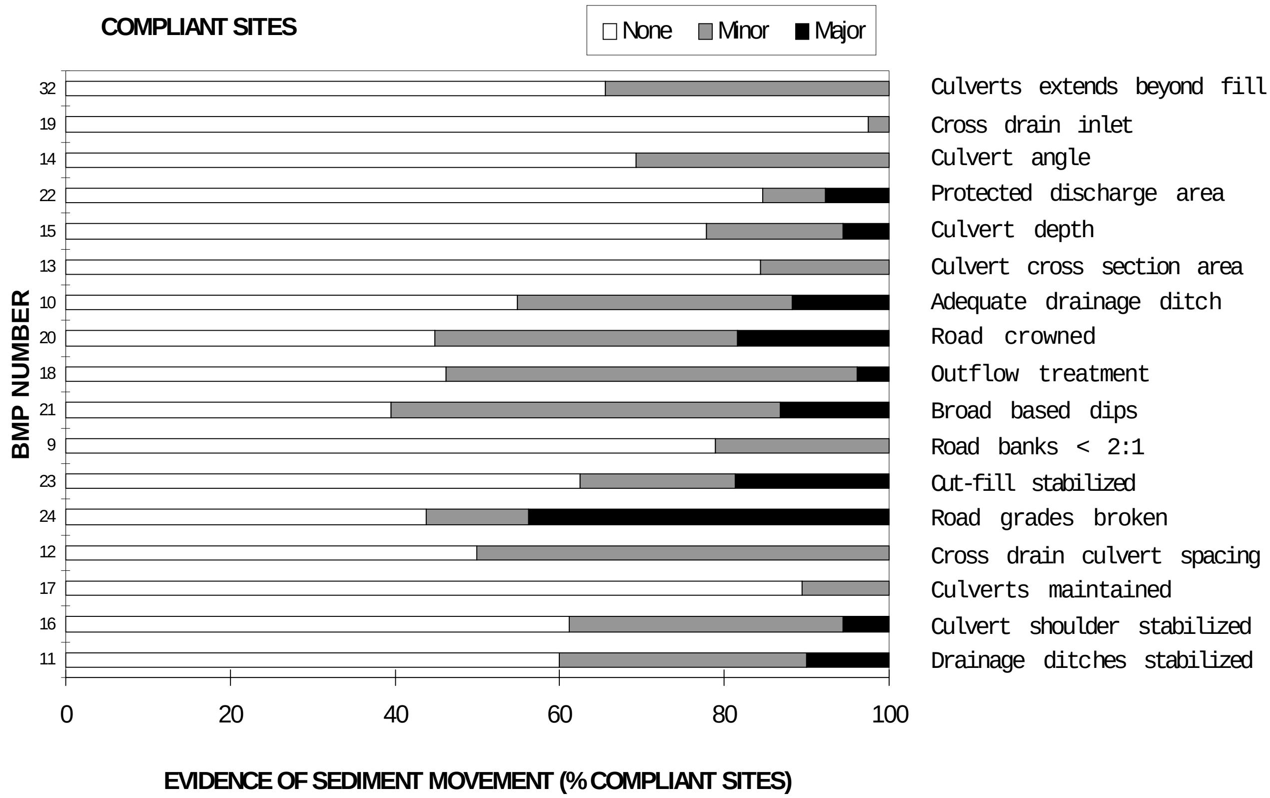
Noncompliance of haul road BMPs tends to be a chronic problem that continues long after harvest operations cease because the roads remain. Eighty-nine percent of the observed cases of sediment movement were judged to be long-term impacts.

Stream Crossings—Compliance

Water features were not present at every site. The number of study sites in which the various stream crossing BMPs were applicable ranged from 16 to 78 (Table 6). Dealing only with those sites where the BMPs were applicable, the percentage of sites in compliance ranged from 94% to 31%. As was the case with haul roads, the BMPs associated with road and trail placement (BMPs 25 and 30) exhibited high levels of compliance. Stream crossings were minimized and streams were not used as skid trails. The statistical precision varied with sample size; 95% confidence bounds widened from 6% to 26% as the number of applicable sites decreased from 78 to 16.

Low levels of compliance (31% to 65%) were observed for a variety of stream crossing BMPs (Table 6). Compliance was lowest for BMP 33 (31%), which applied to 16 of the 120 study sites; logs and brush remaining at 11 sites after completion of the harvest impeded water flow and fish passage. In the majority of these noncompliant cases, slash was placed in small perennial and intermittent streams as a ford for skidder crossing. Although the level of compliance was low for this BMP in the current study, it is important to point out that this practice was a problem on only 9% of the study sites. Retrospective compliance with this BMP (removal of material put into the stream) likely would have generated sediment in response to disturbance associated with removal; the cure may have been worse than the affliction. This problem could have been avoided at the outset by not putting slash in the channel in the first place.

As was the case with haul road cross drains, cross sectional area of culverts used to cross streams was sometimes smaller than the minimum required (15 in). While this may not result in a problem during normal and dry years, there is potential for serious problems in wet years. The single high rainfall events that coincide with spring runoff present a real potential for erosion and sedimentation problems.



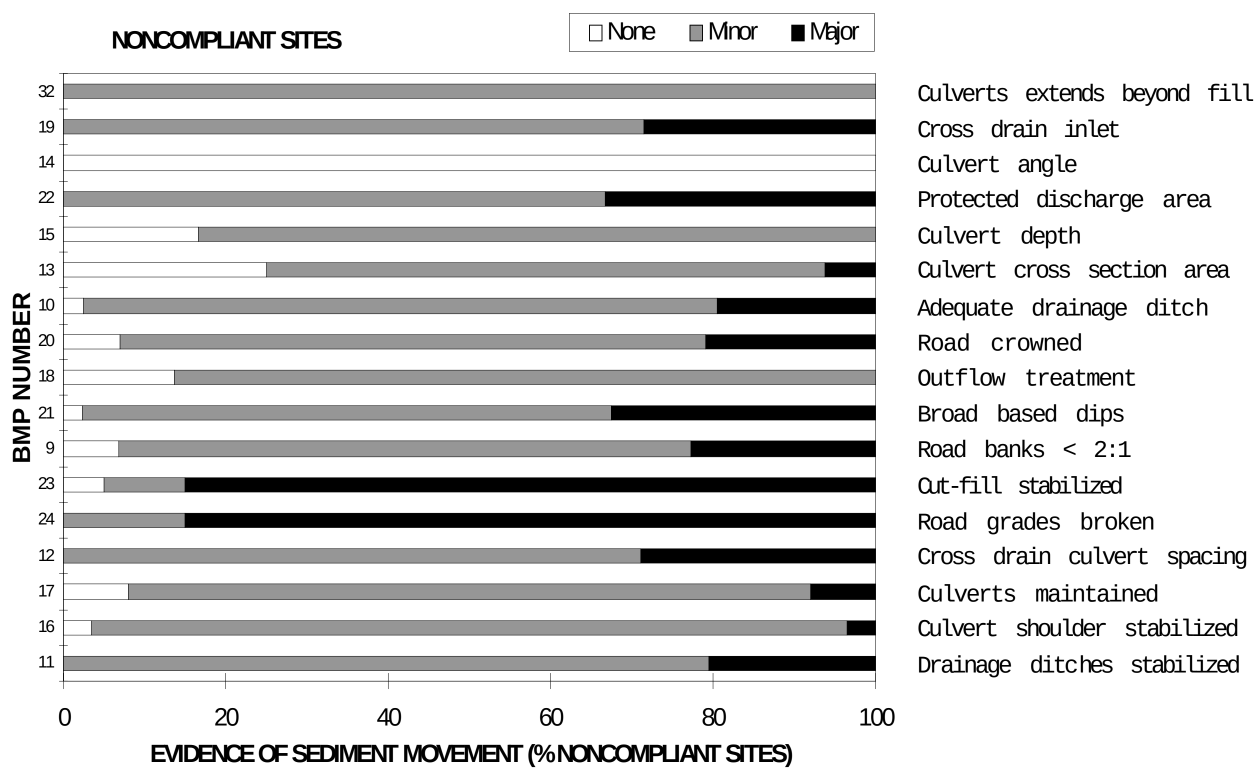


Figure 7. Evidence of sediment movement haul road BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.

Table 6. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for stream crossing BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
78	94 ± 6	NA	25. Minimize stream crossings (p10).
67	91 ± 7	48.60**	30. Watercourses not used as roadways (p7).
60	73 ± 11	32.14**	26. Culverts/bridges used as needed to cross streams.
63	65 ± 12	27.93**	29. Streams crossed at right angle with reasonably level approaches (50′ both sides) (p5).
43	63 ± 15	5.54+	7. Cross sectional area of culvert/bridge adequate (p25, 27).
39	54 ± 16	18.72**	31. Watercourses forded only on hard bottom and banks.
43	54 ± 15	6.12*	28. Culvert/bridge location and placement adequate (p22, 27).
16	31 ± 26	NA	33. Log crossing do not impede water flow or fish passage.

[a]Number of harvested sites where BMP was applicable.
[b]Compliance in percent ± 95% confidence bound.
[c]Chi-square statistic (2 df) testing hypothesis of independence of compliance and evidence for sediment movement (none, minor, major); + denotes rejection at $\alpha = 0.10$; * denotes rejection at $\alpha = 0.05$; ** denotes rejection at $\alpha = 0.01$. Non-significant statistics are not reported; NA denotes not applicable to sediment evaluation.

A variety of deficiencies were encountered in bridge/culvert placement and location, including culverts that were too short, poorly stabilized at the outflow (lacking riprap or vegetation), or substitution of log stringers in place of a culvert or a bridge. A common result of the latter deficiency was deposition of soil directly into streams, especially in loose sandy or sandy loam soils. Logs skidded across stringer bridges drag soil onto the logs and into the stream through the voids. One way to avoid this situation is to use planking in combination with mill felt to prevent movement of soil into the water. Finally, fording of streams was done inappropriately on soft bottoms and banks for 46% of the 39 sites where this BMP was applicable. This latter problem presents a difficult challenge because soft banks are the rule rather than the exception during most of the year and wet, seepy approaches may not freeze in winter. Log crossings are often better than fords, however, the temporary crossings must be removed upon completion of harvesting.

Results for stream crossing BMP compliance in Maine are similar to those reported elsewhere. Brynn and Clausen (1991) reported finding added woody debris in 65% of the streams (two-thirds of which were intermittent) that they examined in Vermont. Phillips et al. (1994) reported departures from culvert size and installation guidelines for 33% of the instances when that BMP was rated in Minnesota. Brynn and Clausen (1991) noted that stream crossings appeared to be the primary source of sedimentation from timber harvesting operations in Vermont. Their data revealed that more than 60% of the stream crossings were made by ford. Sixty percent of skid trail fords had stable approaches and bottoms, a figure that is not dissimilar to the 54% compliance with BMP 31 (water courses forded only on hard bottom and banks) in the current study.

Considering all of the stream crossing practices as a single group across sites, overall compliance with those BMPs was 74% in the current study. This figure represents the proportion of individual stream crossing BMPs rated as either exceeds-meets (4), or minor departure from (3) individual BMPs relative to all of the stream crossing BMPs across the 120 sample sites.

Stream Crossings—Evidence of Sediment Movement

The hypothesis of independence of sediment movement and BMP compliance was rejected for most of those BMPs that could be rated for sediment movement evidence (Table 6). Noncompliance is clearly associated with increases in both incidence and severity of sediment movement. For noncompliant sites, there is a noticeable shift from the majority of sites in the category “none” to the categories of “minor” and “major” which more often characterize the noncompliant sites (Table 7, Figure 8). The use of BMPs does not guarantee that soil will remain in place; there is some sediment movement even with BMP compliance. However, soil only rarely finds a path to surface water when BMPs are used. An interesting exception was provided at one site where a temporary bridge was adequately placed (BMP 28), but the skid trail curved near the approach resulting in sediment being dragged into the stream from the edge of each twitch. The problem of soil being deposited directly into streams between stringers (existing BMPs were complied with) was mentioned previously. Slightly greater than half (58%) of the sediment movement associated with noncompliance of stream crossing BMPs was rated as long-term impact.

Skid Trails—Compliance

The number of study sites in which skid trail BMPs were applicable ranged from 111 to 118 (Table 8). This category contained the greatest number of applicable sites, which is hardly surprising because skid trails are a primary requirement for timber

Table 7. Cross tabulation of stream crossing BMP compliance[a] vs. evidence of sediment movement[b] for sites where stream crossing BMPs were applicable.

BMP	Sediment Movement for Compliant Sites			Sediment Movement for Noncompliant Sites		
	None	Minor	Major	None	Minor	Major
30. Streams not used as roads	58	1	2	0	0	6
26. Culverts/bridges used	32	1	7	0	0	16
29. Right angle stream crossing	28	3	10	1	0	20
27. Cross sectional adequate	24	1	2	9	0	5
31. Hard bottom stream fords	12	2	7	0	0	18
28. Culvert/bridge location	14	9	0	4	14	0
33. Water flow not impeded	3	3	0	3	5	0

[a]Compliant sites rated as 3 or 4; noncompliant sites rated as 1 or 2. Totals may be lower than the number of applicable sites (Table 6) because it was not possible to rate sediment movement for culverts and crossings that were removed.
[b]Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).

harvesting. The statistical precision for the skid trail BMPs was the highest among the five groups examined with 95% confidence bounds all under 10%.

Dealing only with those sites where the BMPs were applicable, the percentage of sites in compliance with skid trail BMPs ranged from 95% to 49%. Compliance with the two BMPs associated with skid trail layout and placement (BMPs 35 and 34) was high (95% and 78%, respectively). As was the case with haul roads, the compliance with the BMP dealing with eliminating the long, unbroken slopes that concentrate flowing water in ruts for deposition downslope could be improved. Application of brush to skid trails and use of skid humps are two practices that can be used to alleviate that problem. However, skid humps are not always used because they may make skidding more difficult. Phillips et al. (1994) reported 62% departure (half minor, half major) from the BMP recommending broad dips and grade rolls for skid trails. Skid trail grade recommendations for Vermont (grades not to exceed 20% for more than 300 ft), which are more liberal than those for Maine, were complied with 97% of the time (Brynn and Clausen 1991).

Wet areas and toe slopes were avoided in only half of the applicable sites in the current study. The presence of wet, fine texture soils ("seepy, silty slopes") continues to pose an interesting challenge because they seldom freeze. Hence, disturbance can be prevented only if they are operated when there is sufficient snow depth. These are the sites where skidders sink readily, displacing soil and leaving large ruts, creating downhill waterways that erode silty soils. Collaboration with forest engineers will be required to adequately address this problem.

Considering all of the skid trail practices as a single group without regard to site, overall compliance with those BMPs was 67% in the current study. This figure represents the proportion of individual skid trail BMPs rated as either exceeds-meets (4), or minor departure from (3), individual BMPs relative to all of the skid trail BMPs across the 120 sample sites.

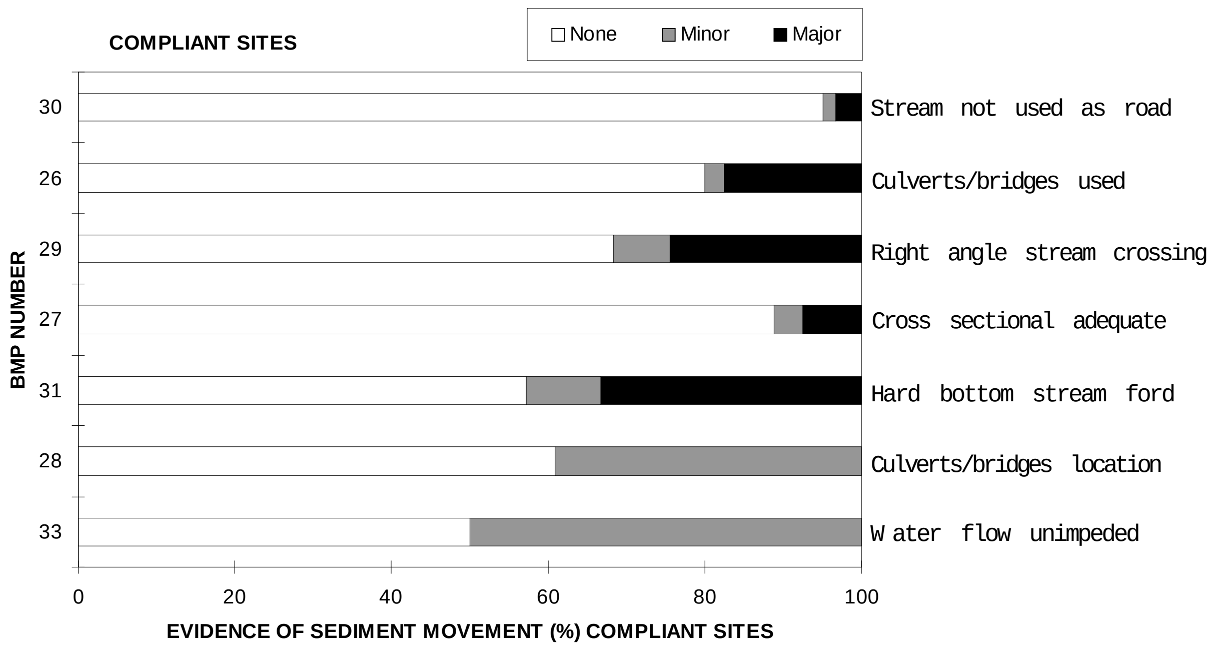
Skid Trails—Evidence of Sediment Movement

The hypothesis of independence of sediment movement and BMP compliance was rejected for all of the BMPs that could be rated for evidence of sediment movement (Table 8). Noncompliance with skid trail BMPs resulted in increased occurrence and severity of sediment movement (Table 9; Figure 9). The majority of compliant sites were characterized by no sediment movement, in sharp contrast to the situation for noncompliant sites. One of the interesting exceptions occurred at one site that was harvested when the ground was frozen, in compliance with BMP 36 (alluded to in the above paragraph). However, skidding left ruts in a small wet area that did not freeze. Compliance in that instance was rated as a minor departure because most of the site was frozen. Sediment originating from that small wet area was delivered to the stream, earning an evidence rating of 1.

Putting Trails and Roads to Bed -- Compliance

The number of study sites in which BMPs for putting trails and roads to bed were applicable ranged from 16 to 98 (Table 10). Compliance ranged from 25% to 88%. The statistical precision for these BMPs was among the lowest of the five groups examined because of the small sample size. The 95% confidence bounds were all greater than 10% and frequently exceeded 20% (Table 10).

When water bars were used, they did intercept water flow. Compliance with BMP 44 was high (88%). However, the water bars could have been installed more effectively; compliance with BMP 42, which recommends that the water bar face extend 12" above and below the road surface, was 71%. One-third of the water bars observed should have extended further beyond the road surface to prevent water from reentering the ditch and should have been installed at a greater angle (30° downslope).



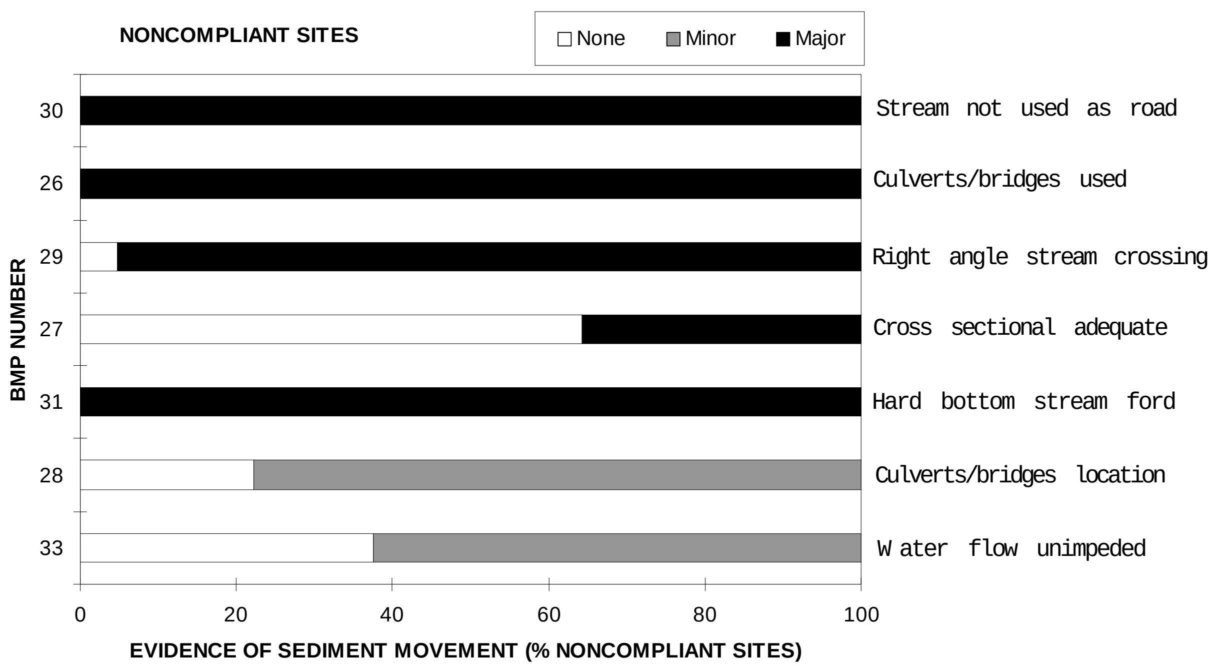


Figure 8. Evidence of sediment movement for stream crossing BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.

Table 8. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for skid trail BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
118	95 ± 4	NA	35. Skid trail distances minimized to < 1/2 mile if possible (p7).
116	78 ± 8	NA	34. Skidding is across the slope where possible, long slopes >10% (esp. downhill), sharp bends avoided (p6).
111	61 ± 9	49.28**	39. Skid humps spaced appropriately and slash used to divert water on steep slopes (> 10%) p17,18).
115	52 ± 9	38.20**	36. Sensitive sites harvested when ground frozen (p6).
119	49 ± 940.	17**	37. Skid trails avoid wet areas and tops and toes of slopes.

[a]Number of harvested sites where BMP was applicable.
[b]Compliance in percent ± 95% confidence bound.
[c]Chi-square statistic (2 df) testing hypothesis of independence of compliance and evidence for sediment movement (none, minor, major); ** denotes rejection at $\alpha = 0.01$; NA denotes not applicable to sediment evaluation.

Table 9. Cross tabulation of skid trail BMP compliance[a] vs. evidence of sediment movement[b] for sites where skid trail BMPs were applicable.

BMP	Sediment Movement for Compliant Sites			Sediment Movement for Noncompliant Sites		
	None	Minor	Major	None	Minor	Major
39. Skid hump spacing	44	23	1	1	27	14
36. Sensitive sites harvested when ground frozen	36	21	3	3	40	11
37. Skid trails avoid wet areas	41	15	2	8	43	9

[a] Compliant sites rated as 3 or 4; noncompliant sites rated as 1or 2. Totals may be lower than the number of applicable sites (Table 8) because it was not possible to rate compliance and sediment movement evidence because the site had been converted to bluberry production.
[b] Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).

Water bars generally were not installed at the density suggested by the BMPs.

Brynn and Clausen (1991) reported only 20% compliance with the AMP for installation and spacing of water bars on skid trails in Vermont. Compliance of 22% was reported for a similar BMP (install water diversion devices on skid trails) in Minnesota (Phillips et al. 1994). Minor departures accounted for 52% and major departures accounted for 18% of the ratings for that particular practice in the Minnesota study.

Steep skid trail sections were not stabilized with vegetation or brush on half of the sites where those features occurred (BMP 47). This deficiency, combined with the need for more water bars, provides opportunity for erosion and sedimentation by allowing water to continue a downward path, increasing erosive forces. Recreational use of ATVs on these skid trails, an impact beyond the direct control of the landowner, sometimes was responsible for disturbing water bars and reducing their effectiveness.

One of the most notable problems was culvert maintenance. Cross drainage culverts were removed on only 25% of sites that were rated, potentially providing ATV access. Over time these culverts become obstructed, reducing their effectiveness for drainage while contributing to erosion of the road banks and surfaces in proximity to the culvert. Phillips et al. (1994) reported 54% compliance with a BMP specifying removal of temporary skid trail crossings prior to spring breakup in Minnesota.

Considering all of the put-to-bed practices as a single group across sites, overall compliance with those BMPs was 54% in the current study. This figure represents the proportion of individual put-to-bed BMPs rated as either exceeds-meets (4), or minor departure from (3) individual BMPs relative to all of the put-to-bed BMPs across the 120 sample sites.

Putting Trails and Roads to Bed--Evidence of Sediment Movement

The hypothesis of independence of sediment movement and BMP compliance was rejected for all of the BMPs that could be rated for evidence of sediment movement. Noncompliance resulted in increased occurrence and severity of sediment movement (Table 11; Figure 10). Seventy-six percent of the sediment movement associated with noncompliance was rated as long-term impact.

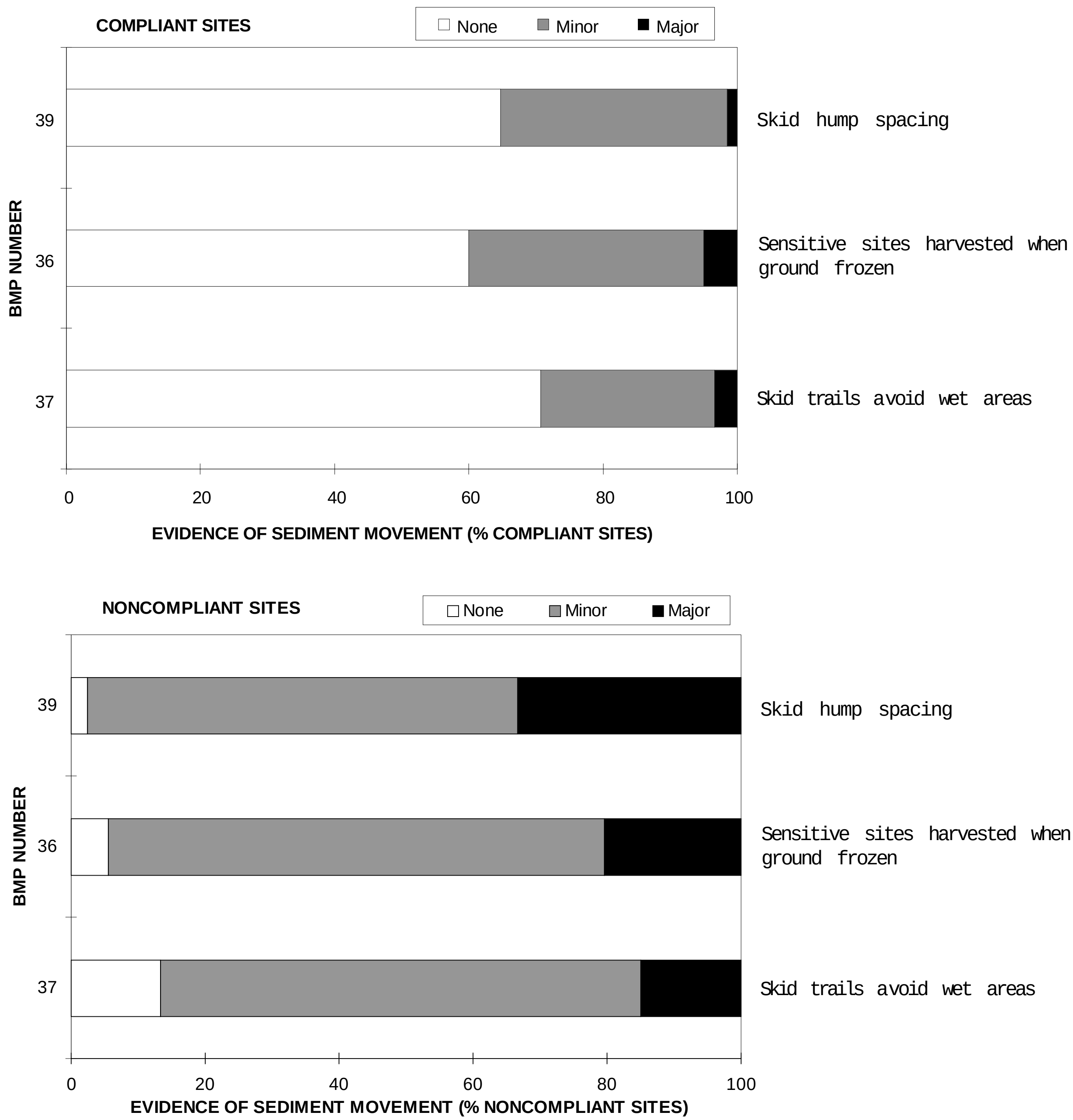


Figure 9. Evidence of sediment movement for skid trail BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.

Table 10. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for putting sites to bed BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
24	88 ± 14	17.90**	44. Water bar intercepts water flow (p19).
24	71 ± 20	11.66**	42. Face of water bar extends 12″ above road surface and 12″ below road surface (p19).
24	67 ± 20	9.45**	45. Water bar outlet extends prevents reentry into ditch or skid trail.
24	62 ± 21		43. Water bars installed 30° angle downslope (p19).
23	61 ± 22	7.50*	46. Rocks, slash or logs disperse and filter water at outlet (p19).
86	54 ± 11	24.98**	47. Steep skid trail sections stabilized with vegetation or brush if needed (p8, 35).
98	39 ± 10	29.71**	41. Adequate spacing of water bars (p18).
16	25 ± 24		40. Cross drainage culverts removed.

[a] Number of harvested sites where BMP was applicable.
[b] Compliance in percent ± 95% confidence bound.
[c] Chi-square statistic (2 df) testing hypothesis of independence of BMP compliance and evidence for sediment movement (none, minor, major); * denotes rejection at $\alpha = 0.05$; ** denotes rejection at $\alpha = 0.01$. Non-significant statistics are not reported.

As was the case with the other BMP groups, there were isolated instances where sediment movement occurred in spite of compliance with the practice. A water bar installed on one site did prevent reentry of water into a ditch (BMP 45). Unfortunately, the water bar funneled sediment laden water directly into a stream earning an evidence rating of one. At a different site, BMP 47 (steep skid trail sections stabilized with vegetation) was complied with due to natural revegetation. However, the slopes were still unstable resulting in some sloughing and sediment delivery to a stream.

Yards and Landings -- Compliance

The number of study sites in which log yard and landing BMPs were applicable ranged from 36 to 120 (Table 12). Most of these BMPs applied because landings and log yards are common to all harvest operations. The statistical precision was high due to the large sample size; 95% confidence intervals were usually under 10%.

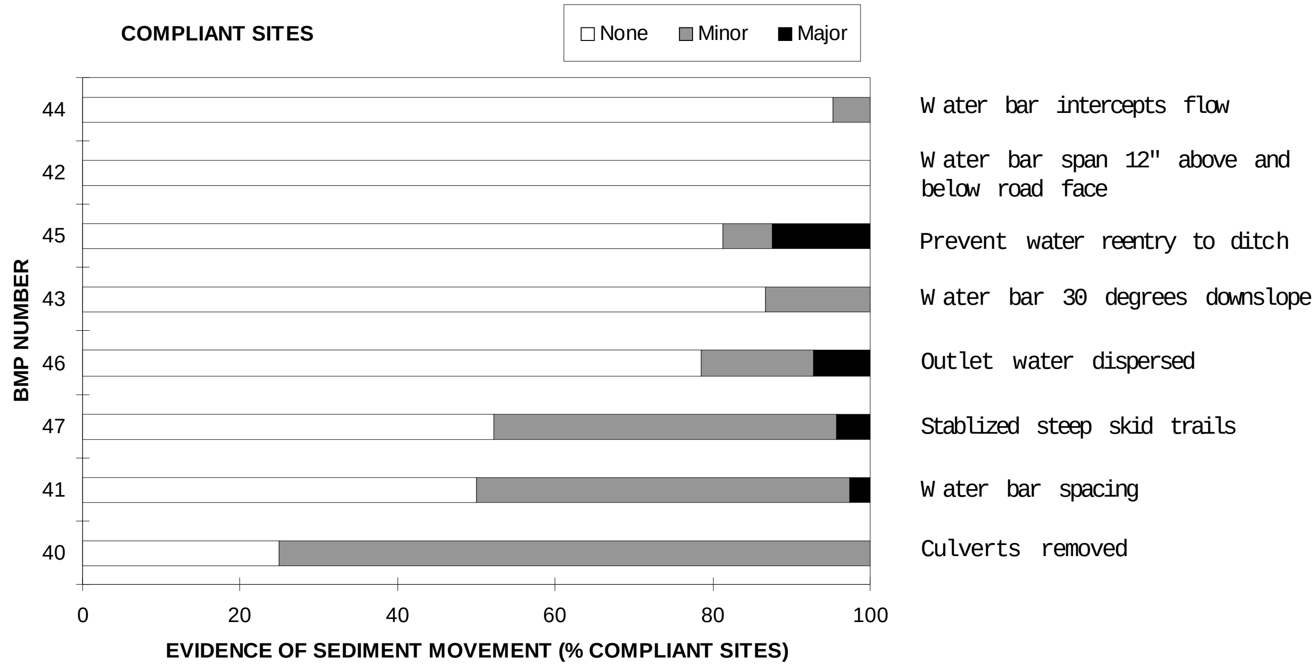
Dealing only with those sites where the BMPs were applicable, the percentage of sites in compliance ranged from 53 to 96%. The degree of compliance was 85% or higher for those BMPs related to landing location and litter (BMPs 48, 51-53). Compliance was lower for those BMPs dealing water diversion and soil stabilization. Two thirds of the sites adequately diverted water out of landings to filter strips. Phillips et al. (1994) reported 92% compliance with the Minnesota BMP recommending drainage of surface water from the combination of landings and skid trails (not separated); there was no specific BMP for preventing water diversion into low lying landings.

Considering all of the yards and landing practices as a single group without regard to site, overall compliance with those BMPs was 81% in the current study. This figure represents the proportion

Table 11. Cross tabulation of putting sites to bed BMP compliance[a] vs. evidence of sediment movement[b] for sites where those BMPs were applicable.

BMP	Sediment Movement for Compliant Sites: None	Minor	Major	Sediment Movement for Noncompliant Sites: None	Minor	Major
44. Water bar intercepts flow	20	1	0	0	2	1
42. Water bar span 12″ above and below road face	17	0	0	3	3	1
45. Prevent water reentry to ditch	13	1	2	2	5	1
43. Water bar 30° downslope	13	2	0	66	2	1
46. Outlet water dispersed.	11	2	1	2	6	1
47. Stabilize steep skid trails.	24	20	2	2	28	10
41. Water bar spacing	19	18	1	3	43	14
40. Culverts removed	1	3	0	1	8	1

[a] Compliant sites rated as 1 or 2; noncompliant sites rated as 3 or 4. Totals may be lower than the number of applicable sites (Table 4) because it was not possible to rate sediment movement for culverts that were removed.
[b] Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).



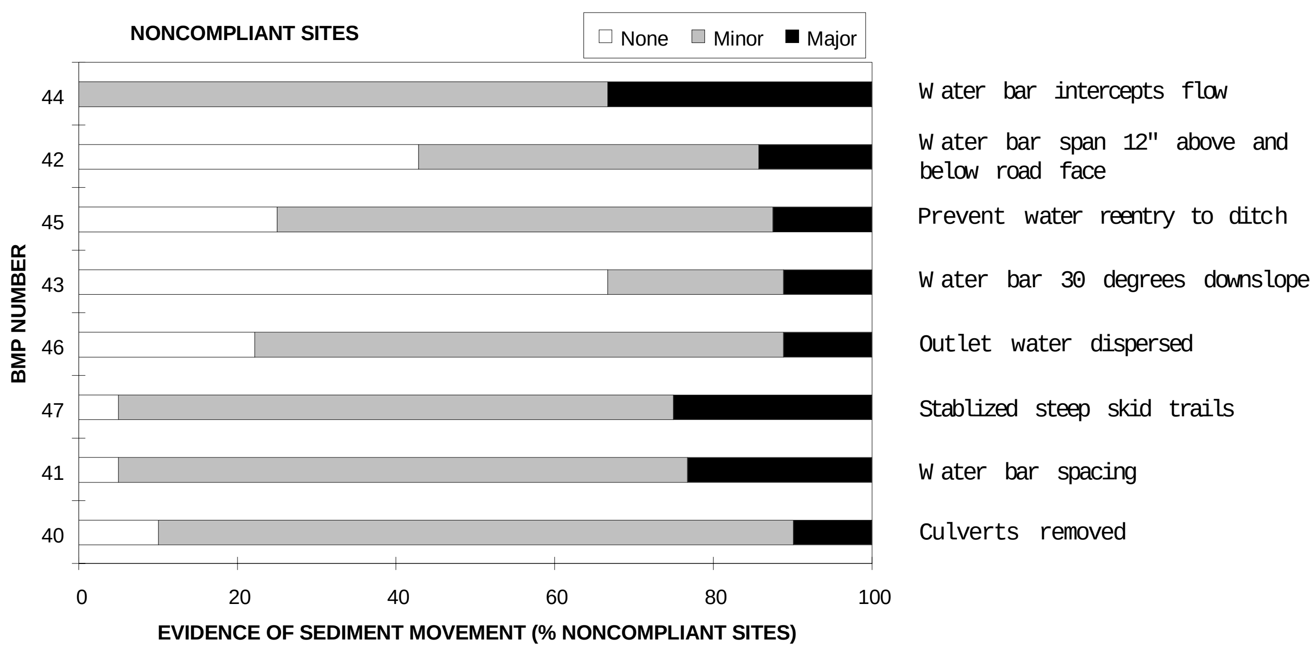


Figure 10. Evidence of sediment movement for putting to bed BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.

of individual yards and landing BMPs rated as either exceeds-meets (4), or minor departure from (3) individual BMPs relative to all of the yards and landing BMPs across the 120 sample sites. As a group, this set of BMPs had the best overall compliance rate. This result parallels those of Brynn and Clausen (1991), who reported high levels of compliance for log landing AMPs in Vermont.

Yards and Landings--Evidence of Sediment Movement

The hypothesis of independence of sediment movement and BMP compliance was rejected for all of the BMPs that could be rated for evidence of sediment movement (Table 12). Noncompliance resulted in increased occurrence and severity of sediment movement (Table 13; Figure 11). The BMP that made the biggest impact on sediment movement was soil stabilization following landing closeout. The shift from no sediment movement to the minor and major sediment movement categories was most dramatic for this BMP. Seventy percent of the sediment movement associated with noncompliance was rated as long-term impact.

One of the exceptions to the association of BMP noncompliance with sedimentation occurred on a site where soil was stabilized after landing closeout (BMP 54) with piles of limbs and tops. Steep sections of skid trail that climbed from the landing into the higher ground were reseeded. However, the steep roadbank around the delimber piles was unstable, sloughing off into the road ditch. In spite of the intensive efforts at this low lying landing on one site, sedimentation occurred.

Streamside Management Zones—Compliance

The number of study sites for which streamside management zone BMPs were applicable ranged from 31 to 73 (Table 14). Significant water features were not encountered at all of the sites, reducing the sample size substantially below 120. Nevertheless, statistical precision for compliance with the majority of BMPs in this group was reasonable; many of the 95% confidence bounds were in the 10% to 11% range (Table 14). There were no specifically recommended AMPs for streamside management zones in Vermont, beyond the requirement for leaving the protective strip itself (Brynn and Clausen 1991).

Dealing only with those sites where the BMPs were applicable, the percentage of sites in compliance with the streamside management zone BMPs ranged from 42 to 78%. Where filter strips were used, slash was kept out of stream channels, and adequate shade was retained over perennial streams on approximately three quarters of the sites where water features occurred. Water from drainage ditches found a path to streams on about half of the sites; some of those filter strips were ineffective (not wide enough) or nonexistent. When sediment barriers (silt fences, hay bales) were used to correct problems, they were not sufficient to prevent silt from entering surface waters for more than half of those instances.

Considering all of the streamside management zone practices as a single group without regard to site, overall compliance with those BMPs was 69% in the current study. This figure represents the proportion of individual streamside management zone BMPs rated as either exceeds-meets (4), or minor departure from (3) individual BMPs relative to all of the streamside management zone BMPs across the 120 sample sites.

Streamside Management Zones—Evidence of Sediment Movement

The hypothesis of independence of sediment movement and BMP compliance was rejected for all of the BMPs that could be rated for evidence of sediment movement (Table 14). Noncompliance resulted in increased occurrence and severity of sediment movement (Table 15; Figure 12). Ineffective sediment barriers (BMP 57) provided the most striking contrast between compliant and noncompliant as the percentage of sites associated

Table 12. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for yards and landings BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
119	96 ± 4	NA	52. No evidence of discarded oil or other fluids (p3).
119	96 ± 4	NA	53. No evidence of litter (p3, 31).
116	90 ± 6	49.42**	51. Landing at acceptable distance from protected area (p3).
120	85 ± 6	NA	48. Landings located on gentle slopes with good drainage (p3).
119	67 ± 8	27.27**	49. Water diverted OUT of landings to filter strips (p3).
109	57 ± 9	31.42**	54. Soil stabilized after landing closeout (p3).
36	53 ± 16	11.96**	50. Water prevented from running INTO low, poorly drained landings (p3).

[a] Number of harvested sites where BMP was applicable.
[b] Compliance in percent ± 95% confidence bound.
[c] Chi-square statistic (2 df) testing hypothesis of independence of compliance and evidence for sediment movement (none, minor, major); ** denotes rejection at $\alpha = 0.01$; NA denotes not applicable to sediment evaluation.

Table 13. Cross tabulation of yards and landings BMP compliance[a] vs. evidence of sediment movement[b] for sites where landing BMPs are applicable.

BMP	Sediment Movement for Compliant Sites None	Minor	Major	Sediment Movement for Noncompliant Sites None	Minor	Major
51. Landings not near protected areas	104	0	0	6	3	2
49. Water diverted Out of landing	56	20	4	7	20	9
54. Soil stabilized	38	22	2	4	33	8
50. No water flow Into landing	15	4	0	3	11	1

[a] Compliant sites rated as 3 or 4; noncompliant sites rated as 1 or 2. Totals may be lower than the number of applicable sites (Table 12) because it was not possible to rate compliance and sediment movement for sites where landings had been regraded with new fill from excavation fill for new roads.
[b] Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).

with major sedimentation shifted from 2% to 81%, respectively (Figure 12). Similarly, termination of drainage ditches directly into surface waters (a specific case of filter strip absence) resulted in marked increases in sediment delivery to streams.

There were a few isolated instances of BMP compliance where sedimentation did occur. One of the sites studied was in compliance with BMP 61 (drainage ditches terminate in filter strips, not surface waters). However, sediment did find a path to the stream at one location. It is important to point out that these instances are isolated. The majority of cases strongly support the general assertion that BMP compliance substantially reduces sedimentation.

BMP Compliance—Organized vs Unorganized Towns

There were no practical differences in BMP compliance between the organized and unorganized townships (Table 16). The sample size available for this comparison was small because not all of the BMPs were applicable on all of the sites. Consequently, we evaluated the difference in mean compliance within each of the BMP groups. For each BMP within each of the six groups, the average proportion of sites on which the BMP was applicable was calculated for each of the unorganized and organized towns. The mean difference in compliance for the BMPs in that group was computed, along with the 95% confidence interval for that difference.

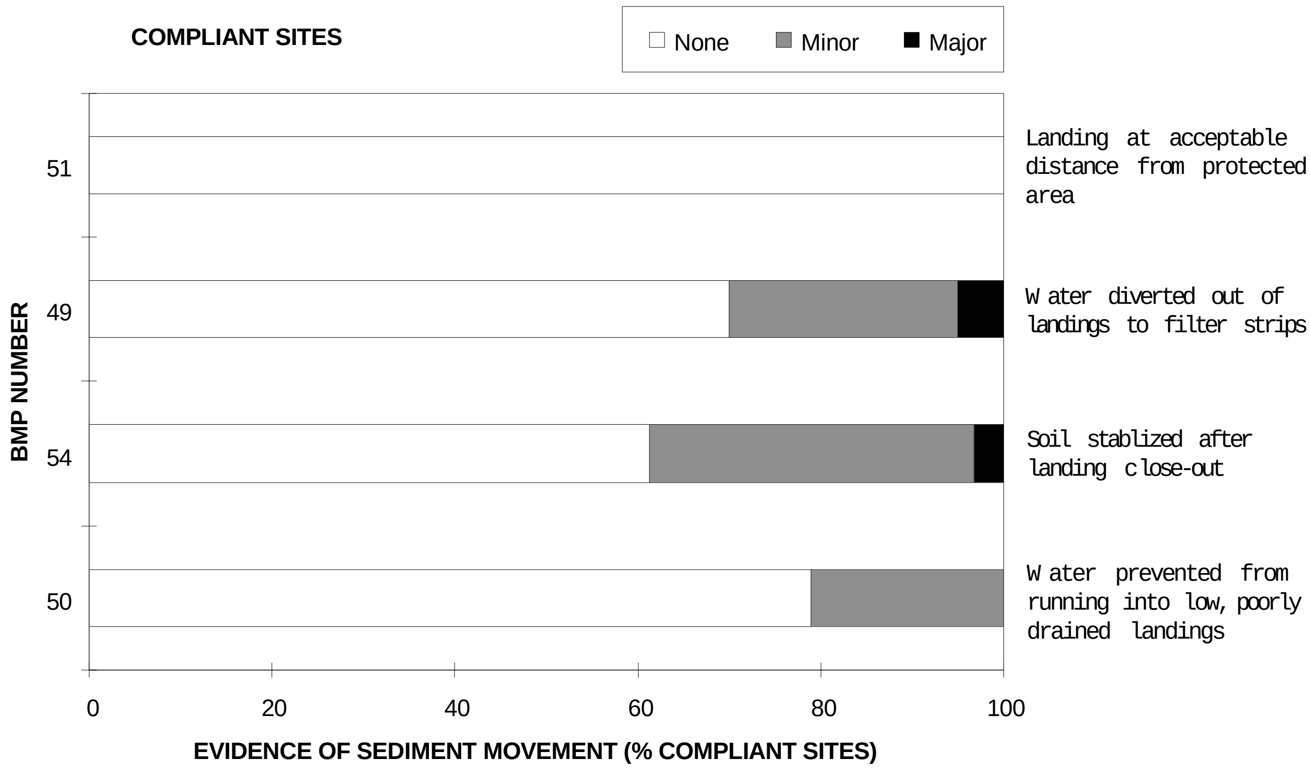
The 95% confidence interval for four of those groups (stream crossings, putting to bed, log yards and landings, streamside management zones) included zero. The confidence interval for mean differences for BMP compliance for haul road (0.04 - 0.14) and skid trail BMPs (0.02 - 0.26) were relatively wide. Although those confidence intervals did not include zero, the lower bounds were very close to zero. Such low values indicate statistical significance but lack any practical interpretation.

One of the factors contributing to statistical significance for compliance with haul road and skid trail BMPs between organized and unorganized towns is the likelihood of encountering more problems on larger sites. The larger harvest areas are located in the unorganized towns (Table 2). There is a weak correlation between harvest acreage and BMP compliance (Table 17). With the exception of one BMP (BMP 56), the statistically significant

Table 14. Compliance (number of sites with rating of 3 and 4 / number of applicable sites) for streamside management zone BMPs.

Applicable sites[a]	Compliance (%)[b]	Chi-square[c]	BMP
63	78 ± 10	NA	55. Adequate shade retained over perennial streams (p33).
73	77 ± 10	55.46**	58. Filter strips used where needed (p15).
68	74 ± 11	25.18**	56. Slash kept out of stream channel (p37).
72	71 ± 11	29.17**	60. Filter strip is adequately vegetated and the duff is undisturbed (p16).
73	67 ± 11	32.92**	59. Filter strip width adequate for slope gradient (p16).
47	55 ± 14	22.84**	61. Drainage ditches terminate in filter strips, not surface waters (p11).
31	42 ± 18	9.25*	57. Sediment barriers effectively used to prevent sediment from entering stream (p40).

[a]Number of harvested sites where BMP was applicable.
[b]Compliance in percent ± 95% confidence bound.
[c]Chi-square statistic (2 df) testing hypothesis of independence of BMP compliance and evidence for sediment movement (none, minor, major); * denotes rejection at a = 0.05; ** denotes rejection at a = 0.01. Non-significant statistics are not reported; NA denotes not applicable.



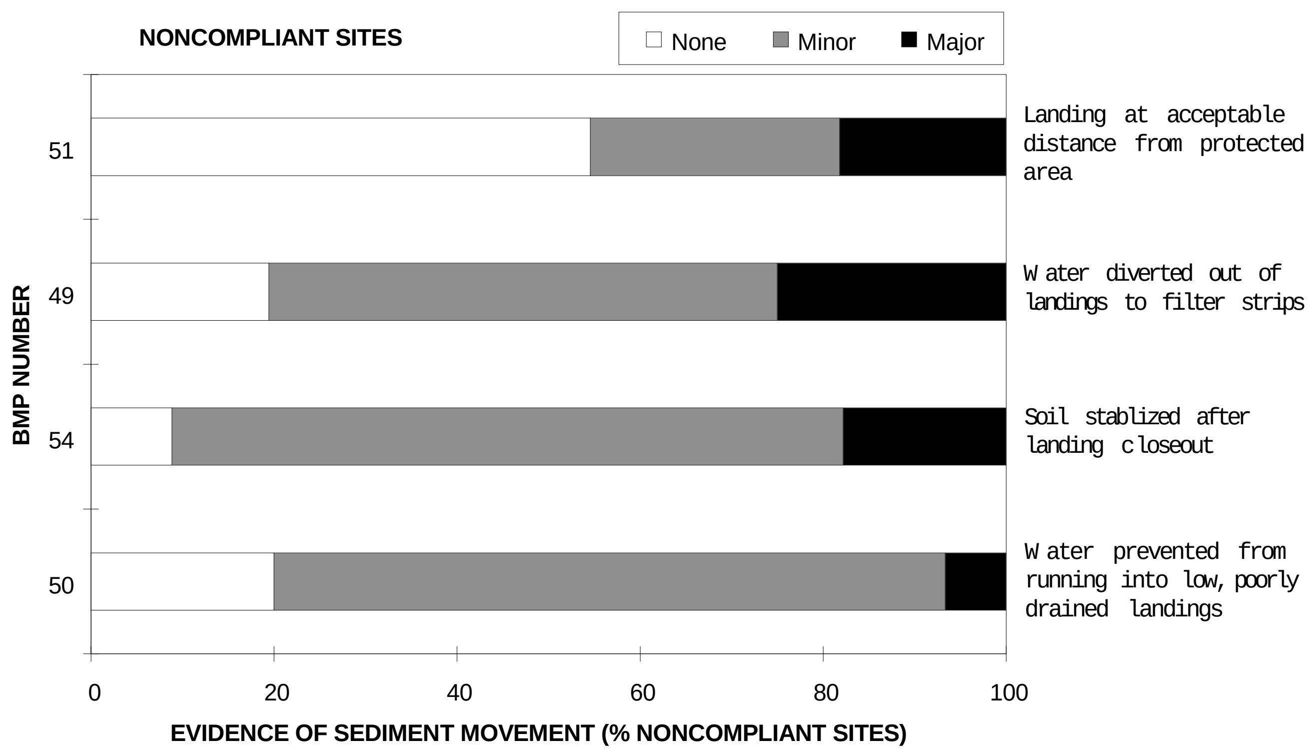
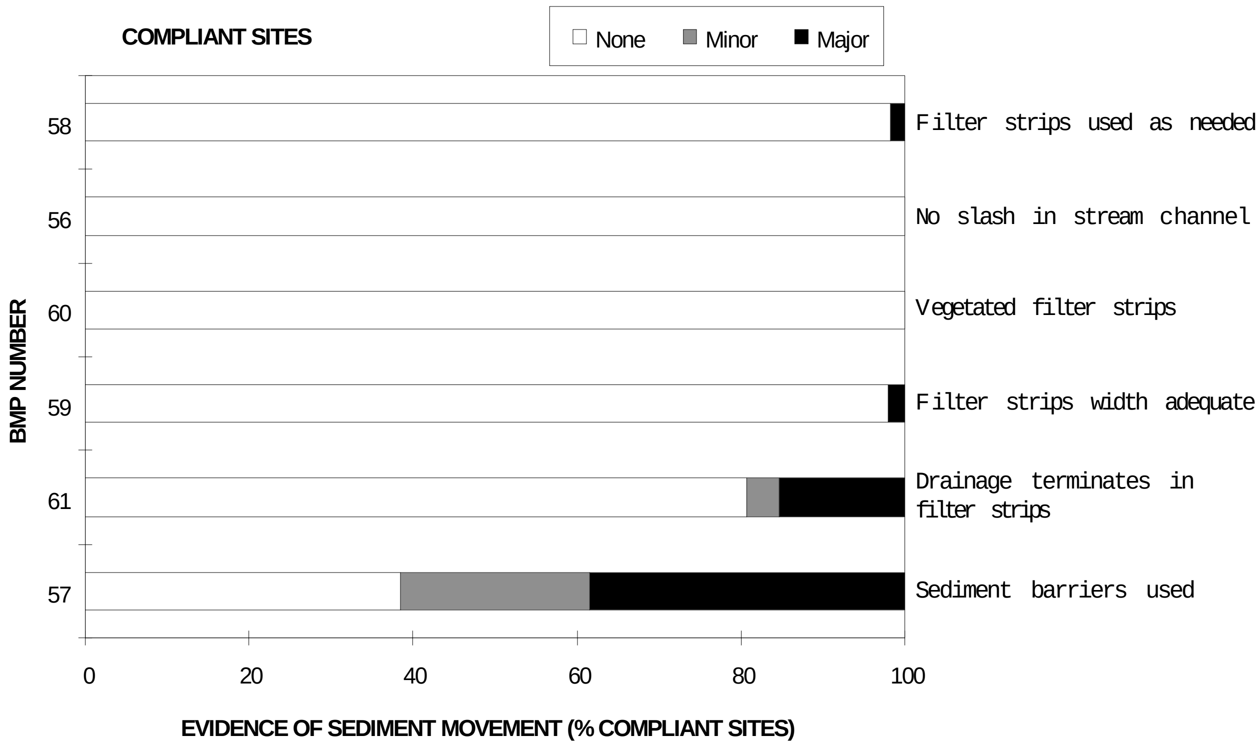


Figure 11. Evidence of sediment movement for landing BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.



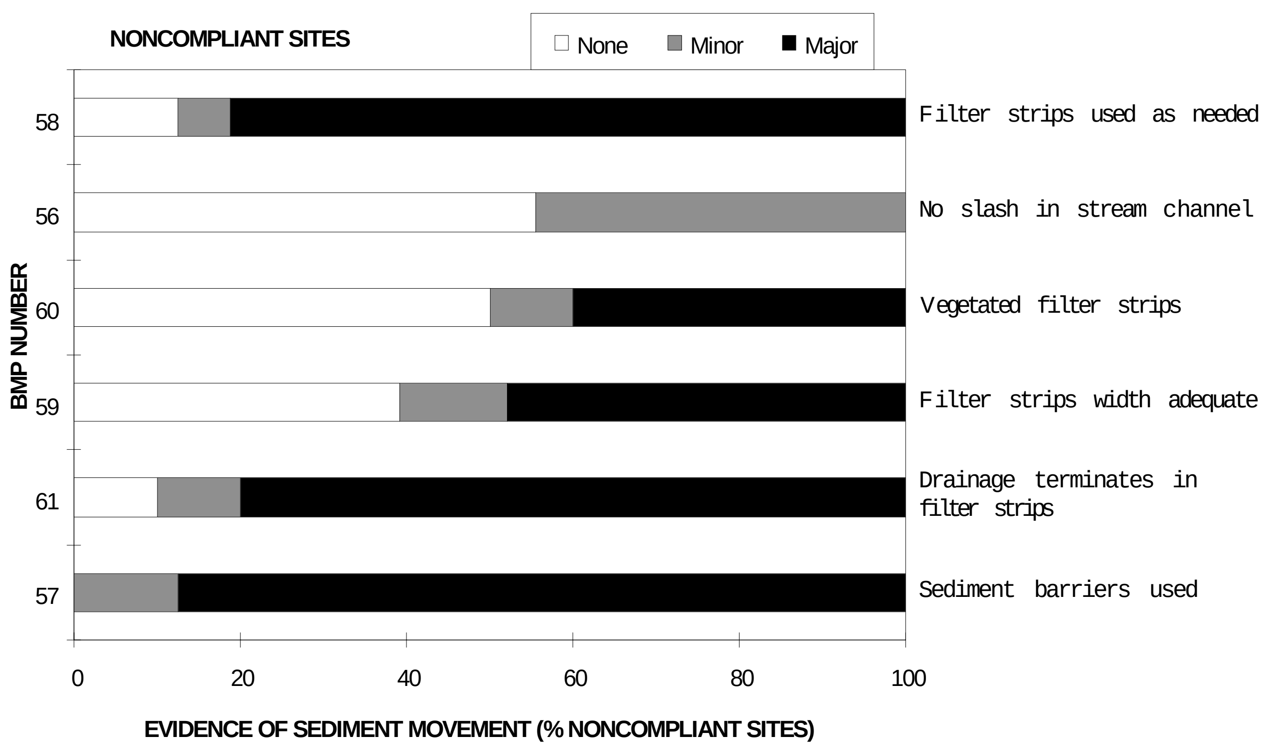


Figure 12. Evidence of sediment movement for streamside management zone BMP compliant and noncompliant sites. None = no sediment movement, minor = movement and no delivery to surface water, major = delivery to surface water.

Table 15. Cross tabulation of streamside management zone BMP compliance[a] vs. evidence of sediment movement[b] for sites where streamside management zone BMPs are applicable.

BMP	Sediment Movement for Compliant Sites			Sediment Movement for Noncompliant Sites		
	None	Minor	Major	None	Minor	Major
58. Filter strips used as needed	55	0	1	2	1	13
56. No slash in stream channel	50	0	0	10	8	0
60. Vegetated filter strips	50	0	0	10	2	8
59. Filter strip width adequate	48	0	1	9	3	11
61. Drainage terminates in filter strip	21	1	4	2	2	16
57. Sediment barriers used	5	3	5	0	2	14

[a]Compliant sites rated as 3 or 4; noncompliant sites rated as 1 or 2. Totals may be lower than the number of applicable sites (Table 12) because it was not possible to rate compliance and sediment movement for some practices on two sites two growing seasons after operations ceased.
[b]Sediment movement ratings were: none = 4, minor = 3, major = 2 or 1 (sediment delivery to surface water).

coefficients were negative (larger acreage associated with noncompliance). The chances of encountering water features and/or difficult topography increase with increasing harvest acreage.

Public Awareness of BMPs

Landowner knowledge of the existence of harvest guidelines tended to be greater in the unorganized towns relative to the organized towns (Table 18). The small sample size (39–51 responses) introduced a low degree of statistical precision; 95% confidence intervals ranged from 11% to 16%. There was a higher degree of landowner familarity with the BMPs themselves and for landowners to require contractors to use BMPs in harvest operations in the unorganized towns. The level of involvement of professional foresters also tended to be higher in the unorganized towns.

These results suggest that an education program is needed to instruct landowners and contractors in the application of BMPs.

Limitations of This Report

This study examined sites within a period of zero to two growing seasons following harvest. Consequently, short-term site impacts that are ameliorated by natural revegetation following harvest were missed. Secondly, there is a degree of subjectivity involved in the compliance ratings, particularly the category of minor departure; it is a concept that is difficult to quantify exactly. The rating system used represents an attempt to capture both the incidence and the quality of BMP implementation of BMP installation. This was attempted by (i) having a single person responsible for rating all of the practices on each site and (ii) field calibration involving the field evaluator and the evaluation team (subset of the Forestry Advisory Team - FORAT) comprised of interested individuals from both the public and private sectors.

The field work component presented a difficult challenge because many of the sites, which were well distributed over the entire state, encompassed hundreds of acres. In most cases, it was impossible to cover a site in its entirety within the four to six hours allotted. The solution was to focus on potential problem areas and work outward from those areas. Isolated problems in low erosion hazard areas (minimal relief and absence of surface waters) may have been missed. However, such areas are not key sources of sedimentation for surface waters.

The population of harvested sites identified using the intent to harvest forms filed with the Maine Forest Service may not include all of the sites actually harvested. There is anecdotal evidence to suggest that the reporting is less than complete. Data provided from inspections by the Maine Forest Service indicates that in 1994, notice of intent har-

Table 16. Difference in the average BMP compliance proportion ($P_{org} - P_{unorg}$) for the five groups of BMPs.

Group	N[a]	P_{org}	P_{unorg}	$P_{org} - P_{unorg}$	95% CI
Haul roads	24	0.73	0.64	0.09	0.04 - 0.14
Stream crossings	9	0.74	0.63	0.11	-0.14 - 0.25
Skid trails	5	0.74	0.60	0.14	0.02 - 0.26
Putting to bed	8	0.65	0.54	0.11	-0.02 - 0.24
Log yards/landings	7	0.84	0.73	0.11	-0.002 - 0.22
Streamside management zones	7	0.67	0.66	0.01	-0.11 - 0.13

[a]Sample size for the t-statistic is the number of BMPs for which mean proportions for compliance were computed for organized and unorganized towns.

Table 17. Spearman rank correlation coefficients (r) between harvest acreage and BMP compliance (1 = no, 2 = yes).

BMP	r[a]
3. Fit road to topography; avoid wet areas and the toes of slopes (p10).	-0.23
5. Avoid flat sections that are difficult to drain (p10).	-0.22
7. Keep roads 75' from streams, 250' from lakes, great ponds (p10).	-0.26
23. Cut-fill stabilized	-0.35
34. Skidding is across the slope where possible, long slopes >10% (esp. downhill), harp bends avoided (p6).	-0.244
3. Water bars installed 30° angle downslope (p19).	0.46
49. Water diverted OUT of landings to filter strips (p3).	-0.16
56. Slash kept out of stream channel (p37).	0.29

[a]Only significant correlation coefficients are reported.

Table 18. Positive responses (with 95% confidence bounds) to survey questions regarding knowledge of BMPs[a].

	Organized Towns		Unorganized Towns	
Survey Question	All Responses	Study Sites	All Responses	Study Sites
Prior knowledge of BMPs (%)	53 ± 14	47 ± 17	69 ± 13	72 ± 14
Familiarity with BMP guidelines (%)	45 ± 14	36 ± 16	67 ± 13	67 ± 15
Require logger BMP compliance (%)	45 ± 14	44 ± 16	63 ± 14	67 ± 15
Professional forester provide advice (%)	65 ± 13	64 ± 16	78 ± 11	79 ± 13
Number of Responses	51	36	49	39

[a]Separated into all potential sites (240) and sites actually sampled (120). Percentage responding positively plus or minus 95% confidence bound.

vest forms were filed for 87% of harvested sites. It is reasonable to expect that at least of a portion of those sites for which notification is not submitted to the state should have a low rate of BMP compliance.

The issue of the potential bias introduced by landowner refusal to allow entry for the scientist performing the BMP compliance assessment is a minor consideration in the current study. Entry was refused only on two properties, which represents less than 2% of the study sites examined. Therefore, it is reasonable to conclude that no bias was introduced to the results from this source.

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