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Idaho Forestry Best Management Practices: Compilation of Research on Their Effectiveness

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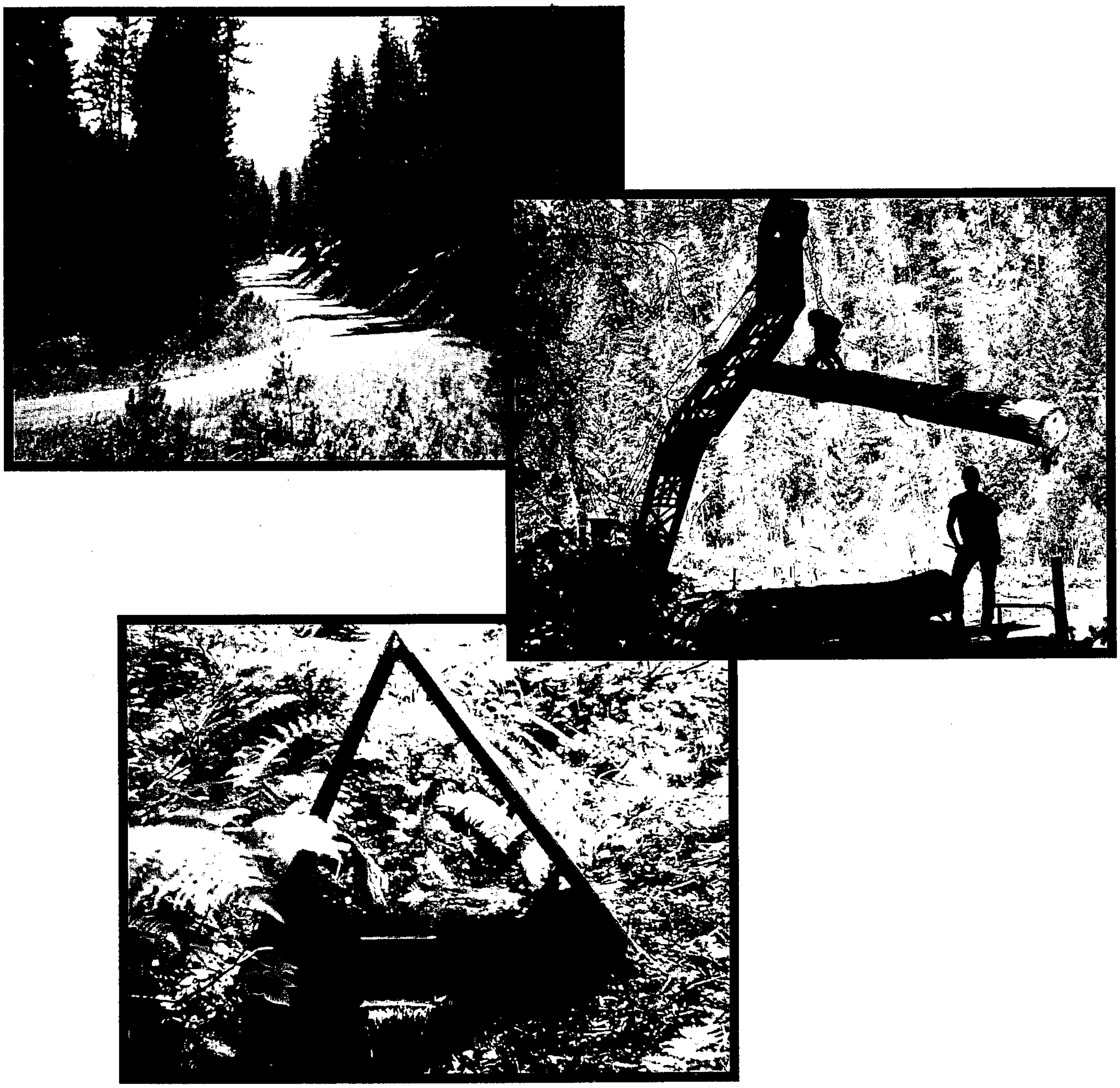

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Research Summary

A search was conducted for quantitative Idaho research results on the effectiveness of the Idaho Forest Practices Act rules and regulations pertaining to timber harvest and forest road construction and maintenance. These rules and regulations are designated as the "best management practices" for the prevention of nonpoint source pollution from silviculture under provisions of the Federal Clean Water Act. For each practice, the relevant research results are summarized; more general summaries for related groups of practices are also provided.

Acknowledgments

I would like to thank my cooperators at the Idaho Division of Environmental Quality (DEQ): Geoff Harvey, Steve Bauer, Donna Rodman, and Bob Steed. Michael McIntyre of the Division of Environmental Quality took special interest in the project; his suggestions and time were greatly appreciated. Special thanks go to my supervisors at the Intermountain Research Station: Walt Megahan, Jack King, and Jim Clayton, for sharing their extensive knowledge of "best management practices" research and for providing their support during this project.

I am particularly grateful to Dannielle Treadwell of the Intermountain Research Station for her cheerful assistance in many of the more tedious aspects of the effort. The Forest Service's FS INFO-Intermountain library system in Ogden, UT, and the University of Idaho library in Moscow were of great help locating copies of publications. I would also like to thank Jim Colla of the Idaho Department of Lands for providing information on best management practices interpretation. The cooperation of Carla Wise, Jay O'Laughlin, and George Belt of the University of Idaho was appreciated. Finally, I would like to thank all those who offered personal and professional support, and the many contacts in government, industry, and academia who shared their time and expertise.

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Introduction

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Background and Need

In 1972, Section 208 of the Federal Clean Water Act Amendments established the regulatory framework for nonpoint source pollution control through use of "best management practices" (BMP's). The responsibility for developing BMP's was delegated to the States. Best management practices are defined in the Idaho Water Quality Standards and Wastewater Treatment Requirements (Idaho Administrative Procedures Act 16.01.2003,01) as "a practice or combination of practices determined by the Department [of Health and Welfare] to be the most effective and practicable means of preventing or reducing the amount of pollution generated by nonpoint sources" (Idaho Department of Health and Welfare 1989).

Idaho was among the first five States to adopt a comprehensive modern forest practices act in 1974 (Henly and Ellefson 1986). The act's purpose was to provide authority for rules "...designed to assure the continuous growing and harvesting of tree species and to protect and maintain the forest soil, air, and water resources, and wildlife and aquatic habitat" (Idaho Forest Practices Act, Title 38, Chapter 13, Idaho Code). Regulated forest practices include timber harvest, road construction and maintenance, reforestation, use of chemicals, and slash management.

Rules and regulations (Idaho Administrative Procedures Act 20.15) are drafted by a Forest Practices Advisory Committee consisting of eight members representing forest land or timber owners, timber operators, fisheries biologists, and informed citizens. Ex-officio members include representatives of the Idaho Division of Environmental Quality, the U.S. Department of Agriculture, Forest Service, the Idaho Farm Bureau, nonindustrial forest landowners, environmental groups, and resource consultants. Executive authority over the rules and regulations is held by the Idaho Board of Land Commissioners, which includes the Governor, attorney general, secretary of state, state auditor, and superintendent of public instruction. Rules and regulations are reviewed yearly and changes are made as necessary. The first set of rules and regulations was issued in 1976.

The Idaho Forest Practices Water Quality Management Plan was completed in 1979 in accordance with Section 208 of the Federal Clean Water Act. This plan identified the rules and regulations associated with the Idaho Forest Practices Act, with recommended modifications, as the approved silvicultural BMP's. The Idaho Division of Environmental Quality is delegated authority to implement the Section 208 requirements, with primary responsibility for evaluating whether the BMP's adequately protect beneficial uses. The Idaho Department of Lands is the designated management agency for State and private lands. The Forest Service and the U.S. Department of the Interior, Bureau of Land Management are the designated management agencies for Federal lands. In 1980, the Idaho Water Quality Standards were amended to identify the Forest Practices Act rules and regulations as the silvicultural BMP's for Idaho (Idaho Department of Health and Welfare 1985, 1989).

Although Idaho had regulated forest practices through the Forest Practices Act rules and regulations since 1976, and although much research had been done in Idaho related to the effectiveness of various BMP's, this research had never been assembled. The Division of Environmental Quality entered into Collection Agreement INT-9084-CA with the Forest Service's Intermountain Research Station in Boise to locate and assemble the available Idaho research information; this report is based on the results of that project.

The Best Management Practices Project

According to the agreement, only quantitative research data collected in Idaho were to be used, and only BMP's in Rules 3 and 4 (Timber Harvest and Road Construction/Maintenance) were to be evaluated. This was solely a compilation of existing research, not a new research study. The requirement that only Idaho data were to be used had advantages and drawbacks. The advantages were in limiting the project's scope and in making sure the data had direct applicability. The disadvantage was that a great deal of research done in other States was automatically eliminated from consideration.

The forest practice water quality BMP's in Rules 3 and 4 were subdivided into individual components to the extent possible. A search for Idaho research results on these individual BMP's was conducted. This included literature searches as well as personal contacts with individuals representing State and Federal agencies, universities, private industry, and others.

A bibliography of potentially useful references was established. References in the bibliography (including literature citations) were screened for applicability. Generally, research measurements onsite or at a nearby downstream point were required. Although instream monitoring studies are useful, they seldom provide a direct measure of the effectiveness of a particular BMP, due to complex channel processes and cumulative effects. For each individual BMP listed under each subrule, the information relevant to that BMP was extracted from the references and included in the report.

The literature searches and interviews revealed that little BMP effectiveness research had been done in Idaho with the exception of the work done by the Intermountain Research Station. (The Station has done research on the effects of various logging and road construction techniques since the 1950's.)

Fewer than 100 references that actually give quantitative effectiveness data on specific BMP's were found; the majority of these were based on Intermountain Research Station data. Many BMP's have not been researched at all in Idaho. Many studies had important implications for various BMP's, but did not provide quantitative effectiveness data. For each BMP, this report gives effectiveness data when available, and may also give relevant information from other research studies.This report includes both English and metric units of measure, depending on the units used in the original research.

The first draft of this report was completed in July 1992. Therefore, relevant research reports written in 1992 or afterward are generally not included in this report.

Format

BMP Summaries

Individual BMP's from Rules 3 and 4 of the April 1990 Rules and Regulations are listed sequentially in the report. Each is identified by its subrule designation within the rules and regulations (for example, Rule 4.c.viii). These designations are not unique, because several BMP's might be listed under a given subrule. Therefore, each BMP was also assigned a unique sequential number to facilitate cross-referencing. These numbers have no significance outside this report. The wording of the BMP's is not taken verbatim from the Forest Practices Act Rules and Regulations; refer to the Rules and Regulations for exact wording.

More recent versions of the Rules and Regulations (May 1992) included a few rules (regarding culvert size and winter operations) that were not included in this report; they were not promulgated when the literature searches were conducted. Other rules may have been added since that time or may be added in the future. For the most part, however, the rules remained constant over the course of this project. Insertion of the culvert size rule resulted in a renumbering of two rules following it (stream crossings and reuse of existing roads). The old numbering system is used in this report; these rules are designated 4.b.vi. and 4.b.vii., respectively. The winter operations rules were added at the end of the road maintenance section, and no renumbering of old rules was involved. Although neither culvert size nor winter operations were included in the literature search, I do not recall seeing any Idaho research on these topics.

For each BMP, all research studies considered relevant to it are listed in chronological order (and alphabetically by author within years). The authors and date are listed first, followed by the study site location. Background information on the study and relevant research results are summarized. Page numbers are given. Although this is somewhat of a departure from the usual scientific reporting style, I felt that this format would be most useful in a reference context.

Following all the listing of research studies for an individual BMP, cross-references may be provided. At the beginning of each subrule (Rule 3.c., Rule 3.d., etc.), a summary of the section is provided.

General Erosion Research Summary

The most common cross-reference is to the General Erosion Research Summary. This section follows the BMP summaries. The research studies summarized there have implications for one or more of the BMP's, but may not address any particular BMP directly. Parts of the information presented there, or other information from the same reference, may also appear under specific BMP's. The information in this section generally addresses general erosion processes, time trends, or seasonal trends. Because this section was not anticipated during the literature search, only general information from references that met the original screening criteria is included.

References

The last section of the report lists complete references for all citations. When applicable, the BMP's where the reference was cited are listed.

Rule 3. Timber Harvesting

Rule 3.c. Soil Protection

Nine BMP's (1 through 9) were evaluated. BMP 1 is general rule 3.c.: "For each harvesting operation, select the logging method and type of equipment adapted to the given slope, landscape, and soil properties in order to minimize erosion."

The remaining BMP's are more specific, and deal with six major concepts:

- Choice of yarding system, specifically, ground versus aerial yarding (BMP's 2 and 3);
- Skid trail gradient (BMP 4);
- Skid trail width (BMP 5);
- Number of skid trails (BMP 6);
- Tractor size (BMP 7);
- Uphill versus downhill cable yarding (BMP 8) and downhill yarding techniques (BMP 9).

Ground Skidding Versus Aerial Yarding

In addition to yarding method, BMP's 2 and 3 also address soil properties (stability, saturation, ease of compaction, and erosion potential), slope gradient (less than or greater than 45 percent), and proximity to streams.

Twenty references were found that address direct or indirect impacts for different yarding systems. Of these, only one (Carlton and others 1982) actually tested for ground skidding versus aerial yarding. This study found no significant difference in onsite surface erosion between skyline- and tractor- logged areas, or even between logged and unlogged areas in the Gospel Hump area near Grangeville (p. 18). The percentage of bare ground was the best predictor of surface erosion on logged and unlogged areas, regardless of yarding method (p. 23).

Seven other references addressed surface erosion associated with various yarding systems. Arnold and Lundeen (1968) evaluated skid trail erosion in the South Fork Salmon River drainage. The estimated average annual erosion depth for 5 years after crawler tractor logging was 0.1 foot (p. 138). McGreer (1981) measured 1-year erosion rates on skid trails near the town of Headquarters. The values varied from 0.003 to 0.583 inches, depending on exposure of subsoil, cover provided by litter or slash, and skid trail gradient (p. 9).

No significant difference in onsite surface erosion was found between skyline and jammer systems in research reported by Packer (1966, p. 695) and by Megahan and Kidd (1972b, p. 139). Megahan and Kidd noted, however, that the skyline system in this study was not used under optimal conditions. Each logging system increased sedimentation in ephemeral drainages by 0.6 times natural rates over a 7-year period (Megahan and Kidd 1972b, p. 140).

Research in the Silver Creek Study Area in the Middle Fork of the Payette River drainage evaluated surface erosion associated with helicopter logging and broadcast burning (Clayton 1981; Megahan 1987; Megahan and others 1995). Clayton (1981, p. 6) reported that accelerated erosion in the first 2 years after logging was limited to 2 percent of the cutting unit area. He estimated that 40 to 60 percent of the erosion volumes of 6.0 and 4.0 tons per acre in the first and second years (respectively) were due to mechanical disturbance associated with logging (pp. 5-6). The total erosion volumes represented an increase over natural erosion of about one order of magnitude (p. 6). Megahan and others (1995) reported accelerated sedimentation (averaging 97 percent) at the watershed mouth persisting for 10 years after treatment. However, this increase was primarily attributed to the effects of broadcast burning on the harsh south aspect Idaho Batholith site.

Soil disturbance is an indicator of the potential for surface erosion. However, soil disturbance is also considered beneficial for conifer regeneration under some circumstances. Six studies investigated soil disturbance associated with various yarding systems. Tractor and tractor-jammer units in the South Fork Salmon River drainage had 88 percent of transect points disturbed, and 40 percent of the points had bare soil (Krassel Ranger District 1983, p. 9).

In the Silver Creek Study Area, Clayton (1990, p. 3) reported soil displacement on 33.5 and 28.5 percent of the total area of units logged with crawler tractors and rubber-tired skidders, respectively. Helicopter logging in the study area caused soil mixing on less than 3 percent of the cutting unit area (Clayton 1981, p. 6).

Leverick (1980, pp. 91-94) and Rummer (1982, p. 107) evaluated mineral soil exposure associated with use of a rubber-tired miniskidder in the University of Idaho Experimental Forest near Moscow. In both studies, soil was exposed on about 12 percent of the area. Bellito's research in the same forest (1985, pp. 39-41, 46, 49, 69) found that deep soil disturbance was generally limited to the corridors for both the Koller (skyline) and KWIK (jammer or high lead) yarding systems. He felt erosion potential was greater on the KWIK units due to a greater number of corridors; disturbance due to the Koller system could be controlled to accommodate natural regeneration.

Mass erosion due to yarding systems is less of a concern than is surface erosion. However, a general statement in one publication could be interpreted to address this issue. Based on a survey of landslides in the Middle Fork Payette River and on the Clearwater National Forest, Megahan and others (1979, p. 132) recommended that logging methods minimize disturbance to the understory to reduce mass erosion frequency.

Soil compaction may decrease productivity or increase erosion. Seven studies were found that evaluated compaction effects of various yarding systems. In the University of Idaho Experimental Forest Bellito (1985, pp. 36, 46-47, 59) found minimal or no significant compaction associated with cable logging (Koller or KWIK yarders) in dry weather. However, in a shelterwood cut logged during wet weather with the KWIK ground lead (double drum jammer configuration), 21 percent of the area was compacted (a bulk density increase of 0.12 grams per cubic centimeter in the corridors), and productivity losses could be expected. The Koller skyline did not cause compaction in wet weather logging except when the skyline cable was not high enough above the slope to keep the logs from dragging on the ground. A single drum jammer near the town of Smith's Ferry resulted in significant compaction on the disturbed areas, with a bulk density increase of 0.29 grams per cubic centimeter or 37.6 percent. Reduced productivity was expected (Bellito 1985, p. 38).

In the South Fork Salmon River drainage, an average of 40 percent of sampling points on tractor and tractor-jammer logged units appeared to be compacted. The compacted sites showed a 26 percent increase in bulk density, with some loss of productivity expected (Krassel Ranger District 1983, p. 9).

Clayton (1990, pp. 3-4) measured bulk density changes associated with crawler tractors and rubber-tired skidders operating in the Silver Creek Study Area near Crouch. He found significant increases in bulk density, ranging from 15 to 29 percent, on all main and secondary skid trails; differences between the two skidder types were not significant. Productivity losses due to compaction were expected on at least two of the three cutting units sampled. A landing in one of the units showed a 32 percent increase in bulk density.

Lenhard (1978, pp. 10, 13) found significant changes in bulk density (14 to 34 percent) associated with 4 to 32 passes of a rubber-tired skidder on volcanic-ash influenced soils near Potlatch; one to two passes did not result in statistically significant changes.

Leverick (1980, pp. xv, 91) and Rummer (1982, pp. 64, 83, 105) assessed the impacts of rubber-tired miniskidders operating in the University of Idaho Experimental Forest. Three of four stands had significant increases in bulk density on skid trails. However, the skid trails covered only 5 to 7 percent of the stand area; compaction was limited to the upper 6 inches of the soil profile; the bulk density values were in the lower half of the critical range, or that range of estimated threshold values for root growth inhibition. Therefore, productivity losses were expected to be minimal.

Froehlich and others (1985, pp. 1016–1017) showed significant and long-lasting compaction associated with ground skidding on volcanic and granitic soils near McCall, for periods ranging from 0 to 25 years after logging and for soil depths from 5.1 to 30.5 centimeters. Initial compaction was about twice as much on volcanic soils; recovery rates were similar on the two soil types.

The most important consideration in the choice of yarding system may be the road system required for support. Several papers addressed the indirect effects related to supporting road systems. Packer (1966, p. 695) and Megahan and Kidd (1972b, p. 140) reported that roads supporting jammer logging resulted in much higher total erosion rates from a jammer-logged watershed than from a skyline-logged watershed with no roads. Kidd and Kochenderfer (1973) noted that jammers required parallel roads every 200 to 400 feet, the corresponding figure for mobile spars for skyline or high lead logging was 1,500 to 2,000 feet. Burroughs and others (1972, p. 11) reported jammer densities exceeding 10 linear miles per square mile, and stressed the critical need to provide proper drainage for the overland flow and subsurface seepage intercepted by the roads.

Megahan (1988, p. 337) summarized existing research to compare the percent of area in roads for various logging systems. The percent of the area in roads ranged from 2.6 to 3.9 percent for skyline logging, from 1.0 to 4.3 percent for tractor logging, and from 25 to 30 percent for jammer logging. Hartsog and Gonsior (1973, p. 13) observed that tractor and jammer skidding can cause disturbance and damage to road prism components, (cutslope, fillslope, tread, and ditch), and prevent correct functioning of the road drainage system.

Skid Trail Gradient

Best management practice 4 says that skid trail gradient should be limited to a maximum of 30 percent on geologically unstable, saturated, highly erodible, or easily compacted soils. Two Idaho studies evaluated skid trail gradient on three soil types: granitic, basalt, and volcanic ash cap. McGreer (1981, p. 6) measured 1-year surface erosion rates on skid trail plots near Headquarters. For comparable plots, increases in slope from 15 percent to 40 or 45 percent increased erosion. At the steeper gradients, erosion increased by factors of 1.2 for the ash-with-litter plots, 1.7 for the ash-without-litter plots, and 3.7 for exposed subsoil plots. However, the effects of the soils, litter, and slash variables were much greater than those of slope.

In Kidd's study on four sites in west-central Idaho (1963, pp. 4-5) slope gradient class (20 to 30, 40 to 50, or 60 to 70 percent) was not significant in the analysis of variance of quantitative erosion data. However, the interaction of soil (basalt or granitic) and slope gradient was significant in analysis of qualitative ratings of erosion control structure effectiveness. Kidd (1963, p. 6) recommended spacing erosion control structures more closely as skid trail gradient increased. Kidd's study (1963, pp. 4-5) showed that more skid trail erosion occurred in ravines than on hillsides, and that skid trail erosion was greater on soils derived from granite than on those derived from basalt.

Skid Trail Width and Number of Skid Trails

In an early study in the Boise Basin Experimental Forest near Idaho City, reported by Haupt (1960, pp. 635-638) and Haupt and Kidd (1965, pp. 665, 668), skid trails were reused whenever possible. Ninety percent of skid trail areas had 50 percent or more mineral soil exposed. However, skid trail soil disturbance is beneficial for regeneration of ponderosa pine. Most of the material eroded from skid trail surfaces was contained in erosion control structures; skid trails stabilized within 4 years. In some cases, there were tradeoffs between area in skid trails and area in roads. Road erosion was a much greater source of stream sedimentation, and roads provided poorer sites for regeneration.

Based on his research on skid trail surface erosion rates on volcanic ash cap soils near Headquarters, McGreer (1981, p. 10) recommended limiting the width of blading of skid trails due to higher erosion rates on exposed subsoils and on soils without litter or slash layers. Clayton (1990, p. 7) and Froehlich and others (1985, p. 1017) recommended limiting the total area in skid trails due to the significant levels of soil compaction observed on skid trails on granitic and volcanic soils.

Clayton (1990, pp. 2, 4) found no significant difference in bulk density between main and secondary skid trails (where secondary skid trails had an estimated 3 to 10 passes), for either rubber-tired skidders or crawler tractors. Lenhard (1978, pp. 10, 22) found significant changes in bulk density on volcanic-ash influenced soils near Potlatch after 4 to 32 passes of a rubber-tired skidder, but not after one to two passes. He recommended that skidder operators disperse their movements rather than concentrate them when working on similar soils. Similarly, Leverick (1980, pp. 88-89) found that bulk densities increased with the number of passes (from 0 to 30) of a rubber-tired miniskidder, with the first 10 trips producing the greatest changes.

Tractor Size

Only one study actually compared the impacts of small and large tractors. In the Boise Basin Experimental Forest, Haupt (1960, pp. 636-638) found that bared areas averaged 34 acres per square mile in skid trails and 19 acres per square mile in haul roads for large tractors (D-8), compared to 17 acres per square mile in skid trails and 33 acres per square mile in haul roads for small tractors (D-4). The relationships between road area and skid trail area for the two tractor sizes varied among silvicultural systems; tractor size effects were not apparent for group selection but were for stem selection.

Leverick (1980, p. 97) and Rummer (1982) tested rubber-tired miniskidders in the University of Idaho Experimental Forest. The Case-Davis Fleethoe 30 was not durable enough for skidding small-diameter trees, but the Case-Davis DH-4 functioned adequately with minimal site impact (including compaction and soil disturbance). See BMP's 2 and 3 for details.

Uphill and Downhill Cable Yarding

No studies actually provided a quantitative comparison of uphill versus downhill cable yarding. Craddock (1967, p. 25) and Megahan and Kidd (1972a, p. 139) noted that downhill cable yarding in the Zena Creek Logging Study Area near McCall increased soil disturbance and surface erosion. Jensen and Finn (1966, pp. 8, 32, 59), based on their hydrologic analysis of the same study area, recommended that road building be limited largely to ridge tops on the decomposed granitic landtype. Logging on these areas would require uphill yarding or roadless logging systems.

No references were found specific to BMP 9, lifting leading ends of logs when downhill cable yarding.

Research Results by Best Management Practice

BMP 1—Rule 3.c. For each harvesting operation, select the logging method and type of equipment adapted to the given slope, landscape, and soil properties to minimize erosion.

See Rule 3.c.i. (BMP's 2 and 3) and Rule 3.c.iii., tractor size (BMP 7).

BMP 2—Rule 3.c.i. Use other than tracked or wheel skidding on geologically unstable, saturated, or easily compacted soils.

BMP 3—Rule 3.c.i. Use other than tractor or wheel skidding on slopes exceeding 45 percent gradient and immediately adjacent to a class I or class II stream, unless the operation can be done without causing accelerated erosion.

These two rules will be considered together, with slope gradients indicated.

Packer 1966, Zena Creek Logging Study Area, Payette National Forest, 67 percent slope gradient—Erosion did not differ on lands logged with jammer and mobile spar high-lead systems 2 years after logging. However, the watershed logged with jammers had almost seven times more sediment in subdrainages because of the road system needed to support the jammer (p. 695).

See Megahan and Kidd (1972b) for this study's completion report.

Arnold and Lundeen 1968, South Fork Salmon River, variable slope gradients, many in excess of 45 percent—Average annual erosion on skid trails was estimated to be 0.1 foot for the first 5 years after crawler tractor logging (p. 138).

Burroughs and others 1972, Idaho-Montana border near Lolo Pass, 23 percent slope gradient—Studies indicated that 1 mile of road in the deep snowpack zone would intercept 310 acre-feet of overland flow and subsurface seepage during the spring snowmelt period. Draining the intercepted water is critical, especially in areas to be logged with jammers, because densities of jammer roads often exceed 10 linear miles per square mile (p. 11).

Megahan and Kidd 1972b, Deep Creek Drainage, Zena Creek Logging Study Area, Payette National Forest (Control Watersheds Oompaul, Hamilton, Tailholt and Circle End Creeks), slope gradient 67 percent—No significant difference was found in onsite erosion between skyline and jammer logging. Skyline logging probably caused more disturbance than usual because the slopes were straight to convex and because the logs were skidded downhill (p. 139).

Jammer and skyline skidding increased sediment deposition in ephemeral drainages an average of 0.04 tons per square mile per day from November 1960 to September 1967. This represented 0.6 times more sediment than measured on the control watersheds. However, the roads supporting the jammer logging caused large increases in sediment, 750 times that measured on the control watersheds (p. 140).

Hartsog and Gonsior 1973, China Glenn Road, South Fork Salmon River drainage, Payette National Forest, most slopes less than 50 percent gradient—Tractor and jammer skidding can cause disturbance and damage to road prism components (cutslope, fillslope, tread, and ditch) and prevent correct functioning of the road drainage system, thus causing serious sedimentation problems (p. 13).

Kidd and Kochenderfer 1973, literature review, slope gradients not specified—Jammer logging required parallel contour roads every 200 to 400 feet (16 miles per section), mobile spar every 1,500 to 2,000 feet (3 miles per section) (p. 285).

Lenhard 1978, near Potlatch, slope gradient not specified—A Clark 666 rubber-tired skidder operating on volcanic-ash influenced soils produced significant changes (ranging from 14 to 34 percent) in bulk density after 4 to 32 passes; one to two passes did not produce significant changes (pp. 10, 13). Bulk densities increased from one to four passes; after four passes, bulk densities were relatively constant (pp. 15-16). Bulk densities did not differ significantly between the treatment year and 1 year afterward, except for the one- and four-pass treatments. The one-pass treatment showed an increase in bulk density between years, and the four-pass treatment showed a decrease (p. 11). Four passes may be a threshold beyond which rapid recovery does not occur (p. 17).

The pore-size distribution index was significantly altered by all treatments except the one-pass treatment (p. 12). The data indicate a redistribution of flow channels for treatments with more than four passes (p. 18). This entails a reduction in macropores critical for plant growth and infiltration processes (p. 22).

Megahan and others 1979, Clearwater National Forest and Middle Fork Payette River Drainage, Boise National Forest, variable slope gradients—Landslide occurrence tended to increase as either tree or shrub crown cover decreased. When crown covers were less than 80 percent, landslide occurrence appeared to be more sensitive to reductions in shrub crown cover than to reductions in tree crown cover. The authors recommended using timber harvest procedures that minimize the disturbance of understory vegetation (p. 132).

Leverick 1980, University of Idaho Experimental Forest, West Hatter Creek and Flat Creek Units, slope gradient not specified—Soil compaction and soil disturbance were evaluated for a Case-Davis Fleethoe 30 converted to a rubber-tired miniskidder for skidding small-diameter trees. On 13 percent of the area mineral soil was exposed enough for erosion to occur (pp. 91-94). Bulk density increased significantly in the top 2 inches of the most heavily traveled skid trail of the Flat Creek unit, but not at soil depths of 4 to 6 inches or 8 to 10 inches. This minimal effect on bulk density was attributed to dry soil conditions at the time of treatment (p. xv, 91). A controlled experiment on the West Hatter Creek unit (with soil moisture varying from 20.38 to 25.32 percent) indicated that compaction was limited to the upper 6 inches of soil (p. xv).

Clayton 1981, Silver Creek Study Area, Control Creek Watershed, Boise National Forest, 30 to 50 percent slope gradients—Helicopter yarding with broadcast burning accelerated erosion on 2 percent of the area, with a short-term increase in erosion volume of approximately one order of magnitude (p. 6). One year after logging, 40 percent of the 6.0 tons per acre of erosion volume was attributed to mechanical disturbance associated with logging; 32 percent was attributed to burning; 19 percent was associated with disturbance but not attributed to a single cause; and 9 percent was attributed to natural causes. During the following year, erosion volume was 4.0 tons per acre, with the percentages attributed to the various causes about the same as in the first year (pp. 5-6).

On 3 percent of the total area, soil horizon mixing was observed. This was attributed to a combination of rodent activity and mechanical disturbance associated with logging (p. 6).

McGreer 1981, near Headquarters, slope gradients up to 60 percent, skid trail gradients 15 to 50 percent—One-year erosion rates were measured on skid trail plots established with a D-6 Caterpillar tractor. The following tabulation was adapted from table 2, (p. 9):

Skid trail gradient	**Soil cover**	**Erosion rate**	
		Tons / acre	*Area inches*
Percent			
15	Ash with litter	0.28	0.003
45	Ash with litter	0.30	0.004
15	Ash without litter	1.00	0.012
45	Ash without litter	1.86	0.022
15	Exposed subsoil	20.46	0.164
40	Exposed subsoil	72.60	0.583
50	Subsoil covered with slash	1.08	0.013

McGreer defined "area inches" as follows: "Area inches assumes an even distribution of erosion throughout the area (plot), which in reality is seldom, if ever, the case. However, the measure is useful as an easy way to visualize the unit."

The author concluded that "ash topsoils are resistant to erosion but exposure of underlying subsoils results in erosion rates severe enough to reduce long-term soil productivity and to create stream sedimentation. Organic litter or slash effectively prevent erosion." [Abstract]

Plots with ash horizons were approaching a zero erosion rate by the end of the first year (p. 6); although erosion rates were decreasing, erosion from plots with exposed subsoils was expected to remain high for at least the second year (p. 7).

Recommendations (p. 10) included:

- Avoid bladed skid trails if possible
- Minimize width and depth of blading where blading is necessary
- Top and limb trees on skid trails to the extent feasible.

Carlton and others 1982, Gospel Hump, slope gradients of logged plots varied from 9 to 53 percent—No significant differences in erosion rates were found between skyline- and tractor-logged plots, or between logged and undisturbed plots (p. 18). Surface erosion was adequately explained by a "percent bare ground" variable alone (p. 23). Predictive equations for seasonal erosion and recovery time for natural mitigation of accelerated erosion (versus percent bare ground) were developed (pp. 24-26).

Rummer 1982, University of Idaho Experimental Forest, Hatter Creek and Flat Creek Units, slopes 10 to 20 percent—A Case DH4 backhoe was converted to a rubber-tired miniskidder to be tested for removing thinning residues. Site impacts were evaluated as part of the study. Three of four stands showed significant increases in bulk density, confined to the upper 6 inches of the soil profile on skid trails (that averaged 5 to 7 percent of the total stand area). Average bulk density values for the upper 6 inches of soil on skid trails ranged from 1.11 to 1.43 grams per cubic centimeter, in the lower half of the critical range (undisturbed areas in the Flat Creek units had bulk densities ranging from 0.93 to 1.12 grams per cubic centimeter in the upper 6 inches). Based on the depth, areal extent, and degree of compaction, the author concluded that there was minimal damage in terms of reduced site productivity (pp. 64, 83, 105).

Soil disturbance studies showed that an average of 79 percent of the total stand area (ranging from 70 to 89 percent) was in the categories "undisturbed" or "litter disturbed but still in place" (p. 107).

This study is a followup to Leverick (1980) and incorporates some of Leverick's data.

Krassel Ranger District, Payette National Forest 1983, Teapot Timber Sale, Krassel Ranger District, Payette National Forest, slope gradients not specified—Line transects of three tractor- and tractor-jammer logged units showed 81 to 100 (average 88) percent of the sampling points were disturbed, 14 to 54 (average 40) percent had bare soil (compared to 2 percent in undisturbed control transects), and 30 to 47 (average 40) percent appeared to be compacted. The compacted sites showed a 26 percent increase in bulk density. Some loss of productivity was expected as a result of compaction (p. 9).

Bellito 1985, Flat Creek Unit of the University of Idaho Experimental Forest, slope gradient 20 to 40 percent, and near Smith's Ferry, slope gradient 80 to 100 percent—Site impacts, including compaction and soil disturbance, were evaluated for a Koller Model K-300 (small skyline yarder), and for a KWIK yarder rigged as a ground lead (double drum jammer) and as a live skyline (in effect a high lead) on the experimental forest. Compaction associated with use of a single drum jammer near Smith's Ferry was also evaluated.

No appreciable compaction occurred during dry weather cable yarding with either the Koller or the KWIK (clearcuts in units 1, 2, and 3 of the experimental forest). Some compaction did occur in the Koller corridors but the area of impact was limited to about 1 percent of the total unit (pp. 46-47). For the two clearcut units yarded with the Koller skyline, there was a small (0.07 grams per cubic centimeter) but significant (alpha = 0.10) increase in bulk density at the corridor centers. Bulk density changes were not significant at 5 or 10 feet on either side of the corridor centers (pp. 35, 62). In the worst case, this would be only 1.2 percent of the total area of the unit having significant compaction (pp. 35, 36, 62). The author felt that no productivity losses due to compaction occurred in the units logged in dry weather (p. 46).

However, compaction was apparent on units logged during wet weather (shelterwood in units 4 and 5 of the experimental forest). The section yarded with the KWIK ground lead had a measured bulk density increase of 0.12 grams per cubic centimeter in the corridors, which was significant at alpha = 0.05. Because the ground lead logging system required more skidding corridors than the skyline system, 21 percent of the total area of the ground lead section was compacted, which would probably result in a loss of productivity (p. 36, 46, 59). Compaction in the Koller skyline section of the shelterwood was limited to one corridor where lack of deflection resulted in a yarding situation similar to a ground lead (p. 46). Higher soil moisture contents during the ground lead yarding may have contributed to the differences in compaction (p. 46).

All of the experimental forest units except one of two Koller clearcuts had enough exposed mineral soil to accommodate natural regeneration. Deep disturbance was generally limited to the corridors (p. 46). Concentration of disturbance in the numerous corridors of the clearcut unit yarded with the KWIK skyline resulted in a higher potential for erosion and sedimentation than in the Koller clearcuts, even though one of these had significantly more exposed mineral soil (pp. 39-41, 69).

At the Smith's Ferry site, bulk density increased 0.29 grams per cubic centimeter (37.6 percent) in areas where the single drum jammer was used. Bulk densities of samples from the logged area were significantly higher (alpha = 0.05) than samples from adjacent undisturbed areas. It was concluded that reduced productivity was likely (p. 38).

The author concluded that the Koller skyline was preferable to the ground lead systems in this study, because it caused no significant compaction on either wet or dry soils when used properly, and had the capability of creating the desired degree of soil disturbance depending on site conditions (p. 49).

Froehlich and others 1985, two sites near McCall, slope gradients: granitic soils 10 to 45 percent; volcanic soils 10 to 35 percent—Bulk densities of granitic and volcanic soils were evaluated on skid trails of ground-skidded, partial-cut areas, and nearby undisturbed areas. Samples were taken at depths of 5.1, 15.2, and 30.5 centimeters at sites ranging from 0 to 25 years since logging (sampled in 5-year age classes).

Compaction was significant and highly persistent on both soil types. The only samples showing full recovery were the three oldest age classes at a depth of 5.1 centimeters on granitic soils. Nearly all other age classes and soil depths showed highly significant differences ($p < 0.01$) between skid trails and undisturbed areas, for both soils. A trend toward recovery was indicated by a significant relationship between time since logging and differences in bulk density (skid trail versus undisturbed) for all but one combination of soil, age, and depth. Recovery was faster at the 5.1 centimeter depth than at the other depths sampled (pp. 1016-1017).

The difference in bulk density between skid trails and undisturbed areas was significantly greater ($p < 0.01$) on the volcanic soils than on the granitic soils. Initial compaction (percent difference in bulk density between skid trails and undisturbed areas) was significantly (nearly two times) greater on the volcanic soil than on the granitic soil, but recovery rates for the two soil types were not significantly different. Therefore, the volcanic soils can be expected to take longer to achieve full recovery (p. 1017).

Megahan 1987, Silver Creek Study Area, Control Creek and Eggers Creek Watersheds, Boise National Forest, average slope gradient 50 percent—After helicopter yarding and prescribed burning, annual sediment yields increased significantly (based on a paired watershed study). The increases, averaging 100 percent, continued to persist 9 years after logging. Years with the highest sediment yields in the control watershed showed the greatest acceleration of sedimentation in the logged watershed. The increases in sediment were attributed to surface and mass erosion in the cutting units; no increases were measured in channel erosion or streamflow (p. 260).

This paper does not separate logging and burning effects; see Clayton (1981) and Megahan and others (1995) for estimation of the relative influences of logging and burning. Megahan and others (1995) is a more complete report of the same study.

Megahan 1988, literature review, variable slope gradients—The amount of area in roads, skid trails, and landings for various logging systems was compared, based on published studies. The Idaho data included: tractor-selection, tractor-group selection, tractor-partial clearcut, jammer-group selection, and skyline-partial clearcut. For tractor logging, the area in roads varied from 1.0 to 4.3 percent, and the area in skid trails varied from 6.7 to 6.8 percent. For jammer logging, 25 to 30 percent of the area was in roads. For skyline logging, 2.6 to 3.9 percent of the area was in roads (p. 337).

Clayton 1990, Silver Creek Study Area, Central Watersheds, Boise National Forest, slope gradients generally less than 40 percent—Three sites were studied for impacts of ground skidding on soils: one with a designated main skid trail, logged by Caterpillar tractor; one with a designated main skid trail, logged by rubber-tired skidder; and one "loggers' choice," with no restrictions other than adhering to BMP's.

Soil displacement was evaluated for main and secondary skid trails, landings, firelines, and "other" categories. Total soil displacement was similar for the three units, but the distribution among the categories varied. The loggers' choice unit had the least skid trail disturbance due to its more circular shape. Total skid trail disturbance was equal for the skidder and tractor units (25 percent); however, there was less displacement in the "other" category for the skidder unit (3.5 percent) than for the tractor (8.5 percent) and loggers' choice (10 percent). This difference was attributed to the additional displacement associated with maneuvering the tractor. Total area with soil displacement was 33.5 percent for the tractor unit, 28.5 percent for the skidder unit, and 27 percent for the loggers' choice unit (p. 3). This can be compared with 1.5 percent displacement (exclusive of landings constructed away from cutting units) associated with helicopter logging in the adjacent Control Creek watershed (Clayton 1981).

Significant increases (ranging from 15 to 29 percent) in bulk density occurred in all skid trail areas of each unit. A significant increase (32 percent) in bulk density also occurred in the landing of the loggers' choice unit (the only landing included in the study). Other areas showed only slight changes in bulk density (pp. 3, 4). Differences between bulk densities on tractor and skidder skid trails were not statistically significant at the 95 percent level (p. 6).

Penetrometer measurements of the tractor and skidder main skid trails and the loggers' choice landing (the only areas tested) all showed significant changes in both surface (0 to 7.5 centimeters) and subsurface (7.5 to 17.5 centimeters) soils (p. 5).

The author concluded that multiple passes with either type of ground skidder (rubber-tired skidders or crawler tractors) resulted in significant soil compaction on coarse-textured granitic soils. On at least two of the three cutting units, the increases in bulk densities for skid trails and landings fell into the monitoring category of "detrimentally compacted," and productivity losses might be expected. In the third unit, the value fell outside the 95 percent confidence interval.

The author recommended the following techniques to minimize the area impacted by ground skidding:

- Restrict skidding to marked trails
- Require directional felling
- Encourage operators to string cables to logs instead of driving to them.

Megahan and others 1995, Silver Creek Study Area, Control Creek and Eggers Creek Watersheds, Boise National Forest, cutting unit gradients 24 to 97 percent, averaging 47 percent—For the 10 years after (clearcut) helicopter logging and prescribed burning, total sediment yield increased significantly ($p < 0.05$), an average of 97 percent. Greatest effects were observed during years with the highest sediment yields.

Active erosion within the cutting units was the apparent source of the accelerated sediment. One progressive mass failure contributed a maximum of 6 percent of the total. The remainder was attributed to accelerated surface erosion resulting from exposure of bare soil on the cutting units. Vegetative cover of shrubs and herbs was still below predisturbance levels 10 years after logging; this was due to the effects of prescribed burning on the harsh south aspect Idaho Batholith site (pp. 22-24). Accelerated erosion and sedimentation generated by prescribed burning on such sites tends to outweigh the benefits gained by helicopter yarding.

The accelerated sedimentation in this study was primarily attributed to burning, not logging. This is a more complete report of the study described in Megahan (1987).

See the General Erosion Research Summary for additional information.

BMP 4—Rule 3.c.ii. Limit the grade of constructed skid trails on geologically unstable, saturated, highly erodible, or easily compacted soils to a maximum of 30 percent.

Kidd 1963, four sites on the Boise and Payette National Forests—Three sites were selected with granitic soil parent material, and one with Columbia River basalt soil parent material. Quantitative and qualitative evaluations were made of erosion on skid trail segments and effectiveness of various erosion control measures (slash dams, log water bars, lop-and-scatter slash). All skid trails were seeded after the control measures were applied. Skid trail slopes varied from 20 to 90 percent (p. 2).

The quantitative data were used to evaluate how the measured erosion volumes varied with slope gradient, structure spacing, and soil parent material. Slope gradient class (20 to 30, 40 to 50, or 60 to 70 percent) was not found significant in the analysis of variance (p. 4).

Analysis of the qualitative structure performance ratings indicated that more skid trail erosion occurred in ravines than on hillsides, and that all the structure types tended to be ineffective in ravines. This was true for both soil types. However, the structure rating value analysis showed that the basaltic soil skid trails showed less erosion than those on granitic soils, with the difference almost significant at the 1-percent level. This may be due to inherent erodibility and productivity characteristics (pp. 4-5). According to the author, "The structure rating values were lower on basalt; this suggests that basaltic soil is inherently less erodible and more productive in growing ground cover that is effective in controlling erosion."

Statistical analysis of the qualitative ratings showed that the interactions of soil and structure treatment and soil and slope gradient were significant at a level between 1 and 5 percent. "This means that soil had a variable effect on the structure performance rating, depending upon the structure used and slope class" (p. 5).

Based on two research studies and the experience of erosion control crews, the author recommended structure spacing by soil parent type (granite or basalt), slope gradient (10 to 70 percent), and topographic location (sidehill or ravine) (p. 6).

McGreer 1981, near Headquarters—One-year erosion rates were measured on skid trail plots established with a D-6 Caterpillar tractor. Measured values, adapted from table 2 (p. 9), were:

Skid trail gradient	**Soil cover**	**Erosion rate**	
		Tons / acre	*Area inches*
Percent			
15	Ash with litter	0.28	0.003
45	Ash with litter	0.30	0.004
15	Ash without litter	1.00	0.012
45	Ash without litter	1.86	0.022
15	Exposed subsoil	20.46	0.164
40	Exposed subsoil	72.60	0.583
50	Subsoil covered with slash	1.08	0.013

For comparable plots, increases in slope from 15 to 40 or 45 percent increased erosion. At the steeper gradients, erosion increased by factors of 1.2 for the ash with litter, 1.7 for the ash without litter, and 3.7 for the exposed subsoil plots (p. 6). However, the effects of the soils, litter, and slash variables were much greater than those of slope (p. 6). Both of the exposed subsoil plots had high erosion rates, even on the gentler slope; all of the volcanic ash topsoil plots had low erosion rates, even on the steeper slopes (p. 10).

See the General Erosion Research Summary for additional information on geologically unstable, saturated, highly erodible, or easily compacted soils.

BMP 5—Rule 3.c.iii. Limit skid trails to the minimum feasible width.

Haupt 1960, Boise Basin Experimental Forest, Boise National Forest—The objective of this research was to determine the type and areal extent of soil disturbance caused by logging activities under various treatments (silvicultural systems, initial stand volumes, reserve volumes, tractor size). If we assume that skid trail width is partially dependent on tractor size, this research has implications for BMP 5. See discussion of the effects of tractor size under this reference in BMP 7 (Rule 3.c.iii., tractor size rule).

McGreer 1981, near Headquarters—One-year erosion rates were measured on skid trail plots established with a D-6 Caterpillar tractor. Measured values, adapted from table 2 (p. 9), were:

Skid trail gradient	**Soil cover**	**Erosion rate**	
		Tons / acre	*Area inches*
Percent			
15	Ash with litter	0.28	0.003
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45	Ash without litter	1.86	0.022
15	Exposed subsoil	20.46	0.164
40	Exposed subsoil	72.60	0.583
50	Subsoil covered with slash	1.08	0.013

The author recommended limiting the width of blading of skid trails due to higher erosion rates on exposed subsoils and on soils without litter or slash layers (p. 10).

Froehlich and others 1985, two sites near McCall—The authors recommended minimizing the area in skid trails due to persistent compaction (more than 25 years) on ground-skidded areas (p. 1017). See summary of this publication under Rule 3.c.i. (BMP's 2 and 3) for details.

Clayton 1990, Silver Creek Study Area, Central Watersheds, Boise National Forest—Three sites were studied for impacts of ground skidding on soils: one with a designated main skid trail, logged by Caterpillar tractor; one with a designated main skid trail, logged by rubber-tired skidder; and one "loggers' choice," with no restrictions other than adhering to BMP's.

Bulk density increased significantly in all areas classified as skid trails in each unit (pp. 3-4). The author recommended limiting skid trail area by designating skid trails, by directional felling, and by stringing cables rather than driving to logs (p. 7).

See the summary of this publication under Rule 3.c.i. (BMP's 2 and 3) for details.

BMP 6—Rule 3.c.iii. Limit skid trails to the minimum feasible number.

Haupt 1960, Boise Basin Experimental Forest, Boise National Forest—The objective of this research was to determine the type and areal extent of soil disturbance caused by logging activities under various treatments (silvicultural systems, initial stand volumes, reserve volumes, tractor size). Areas bared by logging were classified as having more or less than 50 percent of the mineral soil exposed. About 90 percent of the "skidding and associated disturbance" areas had more than 50 percent mineral soil exposed (p. 635). However, the author noted that skid trail disturbance is beneficial for regeneration of ponderosa pine (p. 638).

This study also showed that tradeoffs might exist between area in skid trails and area in roads; see the summary under the next rule (BMP 7) for details. See Haupt and Kidd (1965) for a followup to this report.

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—This article is a followup to Haupt (1960). An attempt was made to minimize erosion associated with logging and logging road construction in 1953 to 1954 by use of "good logging practices," including reuse of skid trails wherever possible (p. 665).

Most skid trail rill erosion occurring on the study area during the first 4 years was contained in the next erosion control structure downslope; after that time skid trails had stabilized due to rehabilitation measures. Sediment from skid trails was delivered to streams only near stream crossings (p. 668).

Lenhard 1978, near Potlatch—On volcanic-ash influenced soils, a Clark 666 rubber-tired skidder was used to test for changes in soil properties as travel intensity increased. Seven sites within one-half acre were randomly assigned treatments of 1, 2, 4, 8, 16, and 32 passes (p. 7).

Significant changes in bulk density (ranging from 14 to 34 percent) occurred for 4 to 32 passes; one to two passes did not produce significant changes (p. 10). Bulk densities increased from one to four passes; after four passes, bulk densities were relatively constant (pp. 15-16). Bulk densities did not differ significantly between years (treatment year and 1 year after treatment) except for the one- and four-pass treatments (p. 11). The one-pass treatment showed an increase in bulk density between years; the four-pass treatment showed a decrease. Four passes may be a threshold value beyond which rapid recovery does not occur (p. 17).

Pore-size distribution index was significantly altered by all treatments except the one-pass treatment (p. 12). The data indicate a redistribution of flow channels for treatments with more than four passes (p. 18). This entails a reduction in macropores critical for plant growth and infiltration processes (p. 22).

On similar soils, the author suggests that skidder operators attempt to disperse rather than concentrate their movements over the harvesting unit (p. 22).

Leverick 1980, University of Idaho Experimental Forest, West Hatter Creek and Flat Creek Units—Soil compaction and soil disturbance were evaluated for a Case-Davis Fleethoe 30 converted to a rubber-tired miniskidder for skidding small-diameter trees.

In the West Hatter Creek unit, experiments were conducted to evaluate bulk density changes at various depths as related to the number of trips (0, 1, 5, 10, 15, 20, 25, or 30) with the skidder (pp. 43, 88). Soil moisture varied from 20.38 to 25.32 percent on the skid trails tested (p. 88). Bulk density varied with number of trips at the 0 to 2 inch depth and at the 4 to 6 inch depth, but changes were not significant at a depth of 8 to 10 inches (p. 89). The first 10 trips produced the greatest changes in bulk density (p. 88), about 13 percent at a depth of 0 to 2 inches and 10 percent at 4 to 6 inches (pp. 132-133).

In the Flat Creek unit, the most heavily traveled skid trail was sampled for bulk density around four points representing various frequencies of travel. Undisturbed areas near each sampling point were also sampled. Samples were taken at depths of 0 to 2, 4 to 6, and 8 to 10 inches (p. 44). Skid trail points were significantly different from nearby undisturbed points only at the 0 to 2 inch depth, probably because of dry soil conditions at the time of the experiment (p. 91). However, there were significant differences among points with different travel frequencies at the 0 to 2 and 2 to 4 inch depths (p. 91).

Froehlich and others 1985, two sites near McCall—The authors recommended minimizing the area in skid trails due to persistent compaction (more than 25 years) on ground-skidded areas (p. 1017). See the summary of this publication under Rule 3.c.i. (BMP's 2 and 3) for details.

Clayton 1990, Silver Creek Study Area, Central Watersheds, Boise National Forest—Three sites were studied for impacts of ground skidding on soils: one with a designated main skid trail, logged by Caterpillar tractor; one with a designated main skid trail, logged by rubber-tired skidder; and one "loggers' choice," with no restrictions other than adhering to BMP's.

Bulk density increased significantly (ranging from 15 to 29 percent) for all areas classified as skid trails in each unit (pp. 3-4). Bulk density did not differ significantly between the main and secondary skid trails on either the tractor or skidder units (p. 4). Secondary skid trails had an estimated 3 to 10 passes (p. 2); this designation was not used on the loggers' choice unit. The author recommended limiting skid trail area by designating skid trails, by directional felling, and by stringing cables rather than driving to logs (p. 7).

See the summary of this publication under Rule 3.c.i. (BMP's 2 and 3) for details.

BMP 7—Rule 3.c.iii. Limit tractor size to the minimum appropriate for the job.

Haupt 1960, Boise Basin Experimental Forest, Boise National Forest—The objective of this research was to determine the type and areal extent of soil disturbance caused by logging activities under various treatments (silvicultural systems, initial stand volumes, reserve volumes, and tractor size). Bared areas in skid trails averaged 34 acres per square mile and haul roads averaged 19 acres per square mile for large tractors (D-8); areas in skid trails averaged 17 acres per square mile, and areas in haul roads averaged 33 acres per square mile for small tractors (D-4) (p. 636).

Some differences in the patterns of disturbance were noted among silvicultural systems. For stem selection, using smaller tractors, road area increased as harvesting intensified (more trees per square mile), while skid trail area remained constant. For the larger tractors, skid trail area increased, while road area remained constant (pp. 637-638). Regression analysis indicated that the total amount of bared area at any given level of harvest intensity might be slightly greater for large tractors than for small tractors under a stem selection system (p. 637).

For group selection, the effects of tractor size on the relative areas in skid trails and roads were not apparent. Areas of disturbance were similar for both tractor sizes, and both skid trail and road disturbance increased as harvesting levels intensified (p. 638). The authors state: "Results of the present study indicate rather conclusively that excessive haul road disturbance is associated with use of small tractors in stem selection cutting" (p. 638).

Skid trail disturbance is beneficial to regeneration of ponderosa pine, while most haul roads offer poor sites for regeneration. Haul roads are useful for providing future access (p. 638).

See Haupt and Kidd (1965) for a followup article with implications for this rule.

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—This is a followup to Haupt (1960). Although the results presented here do not address the tractor size rule, when combined with the results given in the summary for Haupt (1960) there are implications for the rule.

An attempt was made to minimize erosion associated with logging and logging road construction from 1953 to 1954 by use of "good logging practices," including reuse of skid trails, a prohibition on skidding down channels, limited skidding across channels, seeding of skid trails, installation of slash barriers or cross ditches on skid trails, installation of cross ditches on roads, and seeding and harrowing of roads (p. 665).

Most skid trail rill erosion occurring on the study area during the first 4 years (1953 to 1957) was contained in the next erosion control structure downslope; by 1957 skid trails had stabilized due to rehabilitation measures. Sediment from skid trails was delivered to streams only near stream crossings (p. 668). Most sediment heading to and in channels was from haul roads; roadways were revegetated and stabilized by 1958 (p. 668).

Leverick 1980, University of Idaho Experimental Forest, West Hatter Creek and Flat Creek units—The Case-Davis Fleethoe 30 converted to a miniskidder was not durable enough for skidding small-diameter trees. The author suggested that the Case-Davis DH4, a slightly larger utility machine, might be better suited (p. 97). See Rule 3.c.i. (BMP's 2 and 3) for site impacts; see Rummer (1982) for a followup.

Rummer 1982, University of Idaho Experimental Forest, Hatter Creek and Flat Creek units—The Case DH4 backhoe was tested for skidding small-diameter trees, as recommended by Leverick (1980). The DH4 functioned adequately with minimal site impact; see Rule 3.c.i. (BMP's 2 and 3) for details.

BMP 8—Rule 3.c.iv. Uphill cable yarding is preferred.

Jensen and Finn 1966, Zena Creek Logging Study Area, Payette National Forest—A hydrologic analysis of the study area (13,334 acres) was conducted to evaluate watershed conditions and make recommendations (pp. 1, 2). Five landtypes were present; the decomposed granitic landtype was most susceptible to erosion and sedimentation problems. For example, in any watershed, the sedimentation rate was directly proportional to the road mileage constructed in the lands with decomposed granitic soils (pp. 4, 85). Sediment rates as much as 1,000 times higher than normal were measured in some watersheds with decomposed granitic soils (p. 84). Subsurface flows of water are intercepted by roadcuts, interrupting the normal hydrologic function and beginning a cycle of accelerated erosion on these landtypes (pp. 4, 32, 62).

Because of these characteristics, the authors recommended that road building on decomposed granitic soils be limited mostly to ridgetops, unless exposed areas could be completely stabilized, and the hydrologic function could be preserved (pp. 8, 32). Logging on these areas would require logging systems capable of uphill yarding to ridgetop roads, or logging systems that do not require roads (p. 59). They felt that the Skagit Mobile Yarder, a skyline yarder that had been used in the study area, could be used in some situations with minimal watershed damage if roads were built on ridgetops or on stable landtypes (other than decomposed granitics). However, they noted that the Skagit system was not the ultimate for logging of decomposed granitic soils (p. 59).

See Craddock (1967) for further information.

Craddock 1967, Zena Creek Logging Study Area, Payette National Forest—Both downhill and uphill cable yarding were conducted on the study area, using the Skagit Mobile Yarder, a skyline yarder. Although no quantitative erosion data were given, the downhill cable yarding configuration was unsatisfactory. Reasons included ground disturbance, damage to the residual stand, and lack of control. When the uphill yarding configuration was used, soil disturbance was minimal and stand damage was also avoided (p. 25).

Megahan and Kidd 1972b, Deep Creek drainage, Zena Creek Logging Study Area, Payette National Forest—Onsite erosion for skyline and jammer logging were evaluated using erosion plots. No significant differences were found between the two methods; sediment production in ephermeral drainages increased an average of 0.6 times for the 5 years after logging (pp. 139-140). The skyline system probably caused more disturbance than usual because the slopes were straight to convex, rather than concave, and because the logs were skidded downhill rather than uphill (p. 139).

BMP 9—Rule 3.c.iv. When downhill cable yarding is used, take reasonable care to lift leading ends of logs to minimize downhill movement of slash and soils.

No references were found specific to lifting leading ends of logs; see the previous rule (BMP 8) for general observations regarding downhill cable yarding.

Rule 3.d. Location of Landings, Skid Trails, and Fire Trails

Seventeen BMP's (10 through 26) were evaluated. These BMP's deal with four major concepts:

(1) The location of landings, skid trails, and fire trails relative to:
  - Site stability
  - The stream protection zone
  - Amount of sidecasting (BMP's 10 through 17);

(2) Landing size (BMP 18);
(3) Inclusion of slash or stumps in landing fill material (BMP's 19 and 20);
(4) Stabilization of landings requiring sidecasting by (BMP's 21 through 26):
  - Seeding
  - Compaction
  - Riprapping
  - Benching
  - Mulching
  - Other suitable means.

No references were found that specifically dealt with these topics in the context of landings, skid trails, and fire trails. However, information on stable areas is in the General Erosion Research Summary. For BMP's 19 through 26, see the corresponding BMP's under Rule 4.c., Road construction.

Research Results by Best Management Practice

BMP 10—Rule 3.d. Locate landings on stable areas to prevent the risk of materials entering streams.

See Rule 3.d.i., landing location rule (BMP 13), and the General Erosion Research Summary.

BMP 11—Rule 3.d. Locate skid trails on stable areas to prevent the risk of materials entering streams.

See Rule 3.d.i., skid trail location rule (BMP 14), and the General Erosion Research Summary.

BMP 12—Rule 3.d. Locate fire trails on stable areas to prevent the risk of materials entering streams.

See Rule 3.d.i., fire trail location rule (BMP 15), and the General Erosion Research Summary.

BMP 13—Rule 3.d.i. Locate all new or reconstructed landings on stable areas outside the appropriate stream protection zone.

See the General Erosion Research Summary; no specific references were found.

BMP 14—Rule 3.d.i. Locate all new or reconstructed skid trails on stable areas outside the appropriate stream protection zone.

See the General Erosion Research Summary; no specific references were found.

BMP 15—Rule 3.d.i. Locate all new or reconstructed fire trails on stable areas outside the appropriate stream protection zone.

See the General Erosion Research Summary; no specific references were found.

BMP 16—Rule 3.d.i. Locate fire trails where sidecasting is held to a minimum.

No references were found.

BMP 17—Rule 3.d.i. Locate skid trails where sidecasting is held to a minimum.

No references were found.

BMP 18—Rule 3.d.ii. Minimize the size of landings to that necessary for safe economical operation.

No references were found.

BMP 19—Rule 3.d.iii. Keep fill material used in landing construction free of loose stumps to prevent landslides.

No references were found specific to landings; see rule 4.c.iv., woody materials in roadfills (BMP 127).

BMP 20—Rule 3.d.iii. Keep fill material used in landing construction free of excessive slash to prevent landslides.

No references were found specific to landings; see rule 4.c.iv., woody materials in roadfills (BMP 127).

BMP 21—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: seeding (first alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by seeding (BMP 117).

BMP 22—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: compaction (second alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by compaction (BMP 118).

BMP 23—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: riprapping (third alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by riprapping (BMP 119).

BMP 24—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: benching (fourth alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by benching (BMP 120).

BMP 25—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: mulching (fifth alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by mulching (BMP 121).

BMP 26—Rule 3.d.iii. On slopes where sidecasting is necessary, stabilize landings by use of: other suitable means (sixth alternative).

No references were found specific to landings; see rule 4.c.iii., stabilization of exposed material by other suitable means (BMP 122).

Rule 3.e. Drainage Systems

Seventeen BMP's (27 through 44) were evaluated. Best management practices 27 through 29 are the general rule 3.e.: For each landing, skid trail, and fire trail, provide and maintain a drainage system that will control the dispersal of surface water in order to prevent sediment from damaging Class I streams.

Practices 30 through 41 suggest six alternatives for stabilizing skid trails and fire trails:

- Water bars (BMP's 30 and 36);
- Cross drains (BMP's 31 and 37);
- Outsloping (BMP's 32 and 38);
- Scarification (BMP's 33 and 39);
- Seeding (BMP's 34 and 40);
- Other suitable means (BMP's 35 and 41).

Practices 42 through 44 address achieving landing drainage and stabilization through:

- Reshaping (BMP 42);
- Establishing ground cover (BMP 43);
- Other means (BMP 44).

No research was found on fire trail stabilization. Only one reference was found on landing drainage. Clayton (1990, p. 7) noted that standard rock rippers did not adequately reduce subsoil compaction on a landing in the Silver Creek study area. He recommended that other implements be tested.

Froehlich and others (1985, p. 1017) recommended scarifying skid trails because of the long-term compaction observed in their research.

Kidd (1963, pp. 4-6) found that log water bars were more effective than slash dams, or lopping and scattering slash, for controlling erosion on seeded skid trails with soils derived from granite or basalt. Cross ditches could be substituted for log water bars if every third or fourth structure remained a log water bar. All structures were generally ineffective in ravines.

Haupt and Kidd (1965, p. 668) noted that both slash barriers and cross ditches were generally effective in containing sediment on seeded skid trails in the Boise Basin Experimental Forest.

McGreer (1981, p. 9) found that, for skid trails with the volcanic ash topsoils intact, leaving a remnant litter layer reduced first-year erosion 72 percent on 15 percent gradient skid trails, and 84 percent on 45 percent gradient trails. For skid trails with the volcanic ash topsoil bladed away and the alluvial subsoils exposed, first-year erosion was reduced by placing slash on the skid trail. Erosion on the slash-treated, 50 percent gradient skid trail was 98.5 percent less than on a 40 percent gradient skid trail without slash, and 94.7 percent less than on a 15 percent gradient skid trail without slash. Skid trails with exposed alluvial subsoils without slash treatments had much higher erosion rates and slower recovery than skid trails on volcanic ash topsoils.

Gray and Megahan (1981 p. 21) recommended leaving undisturbed vegetation below skid trails and other disturbed areas to spread water and reduce the likelihood of mass erosion.

Research Results by Best Management Practice

BMP 27—Rule 3.e. For each landing, provide and maintain a drainage system that will control the dispersal of surface water in order to prevent sediment from damaging Class I streams.

Gray and Megahan 1981, Pine Creek, Boise National Forest—Based on their analyses of slope stability in the Idaho Batholith, the authors recommend leaving undisturbed vegetation to provide water-spreading areas large enough to accommodate water draining from roads, skid trails, and other disturbed areas (p. 21).

BMP 28—Rule 3.e. For each skid trail, provide and maintain a drainage system that will control the dispersal of surface water in order to prevent sediment from damaging Class I streams.

Gray and Megahan 1981—See discussion under BMP 27.

See Rule 3.e.i., skid trail drainage (BMP's 30 through 35).

BMP 29—Rule 3.e. For each fire trail, provide and maintain a drainage system that will control the dispersal of surface water in order to prevent sediment from damaging Class I streams.

Gray and Megahan 1981—See discussion under BMP 27.

See Rule 3.e.i., fire trail drainage (BMP's 36 through 41).

BMP 30—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: water barring (first alternative).

Kidd 1963, four sites on the Payette and Boise National Forests, three granitic, one basaltic—Various skid trail erosion control methods (lopping and scattering slash, slash dams, and log water bars) were tested on two soil parent materials, granite and basalt (p. 1). All skid trails were seeded after installation of erosion control structures (p. 2). Qualitative effectiveness ratings were assigned with 1.0 completely effective and 4.8 completely ineffective (p. 3).

Effectiveness ratings of the various structures were not significantly different in analysis of variance because of the general ineffectiveness of all types of structures in ravine bottoms (pp. 4–5). Water-diverting structures (log water bars and cross ditches) were generally more effective than the sediment-filtering methods (slash dams and lopping and scattering of slash) (p. 5).

Effectiveness of the various structures was analyzed relative to soil parent material, sidehill versus ravine, and percent of slope. Overall, log water bars were most effective, with ratings of 1.78 on granitic soils and 1.54 on basaltic soils, compared to ratings of 2.15 (granitic soils) and 2.25 (basaltic soils) for slash dams, and 2.93 (granitic soils) and 1.60 (basaltic soils) for lopping and scattering of slash (p. 5).

Slash dams were not recommended for use on sidehills due to their high relative cost and their inability to divert water; they also deteriorate and become ineffective in 1 or 2 years. Log water bars do an excellent job of diverting water on either flat or shallow, trough-shaped sidehill skid trails. Cross ditches can be substituted for log water bars, but are prone to sloughing; every third or fourth structure should be a log water bar to divert water. Cross ditches are the least expensive. Lopping and scattering of slash was recommended for gentler slopes with minimal potential for surface flow undercutting. Recommendations are given for spacing of structures based on slope gradient, soil parent material, and sidehill versus ravine (p. 6).

BMP 31—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: cross draining (second alternative).

Kidd 1963—See Rule 3.e.i., stabilization of skid trails by water barring (BMP 30).

Haupt and Kidd 1965, Boise Basin Experimental Forest, near Idaho City—On seeded skid trails with slash barriers or cross ditches, sediment from rills was generally contained by erosion control structures during the first 4 years; after that, skid trails had stabilized. Skid trail sediment reached streams only near stream crossings (p. 668). No quantitative effectiveness data were given.

BMP 32—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: outsloping (third alternative).

No references were found.

BMP 33—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: scarifying (fourth alternative).

Froehlich and others 1985, two sites near McCall, one granitic, one volcanic—The authors recommend scarifying skid trails because of persistent compaction (more than 25 years) on ground-skidded areas (p. 1017). See Rule 3.c.i. (BMP's 2 and 3) for details.

BMP 34—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: seeding (fifth alternative).

Kidd 1963—See rule 3.e.i., stabilization of skid trails by water barring (BMP 30); seeding was used in conjunction with other methods tested rather than being tested separately.

Haupt and Kidd 1965—See rule 3.e.i., stabilization of skid trails by cross draining (BMP 31); seeding was used in conjunction with other methods rather than being tested separately.

See the General Erosion Research Summary regarding the effectiveness of vegetation and other ground cover in reducing erosion.

BMP 35—Rule 3.e.i. Keeping current, stabilize erosion-prone skid trails by: other suitable means (sixth alternative).

Kidd 1963—See rule 3.e.i., stabilization of skid trails by water barring (BMP 30) for a discussion of the effectiveness of slash dams and lopping and scattering slash.

Haupt and Kidd 1965—See rule 3.e.i., stabilization of skid trails by cross draining (BMP 31), for a discussion of the effectiveness of slash barriers.

McGreer 1981, near Headquarters—For skid trails with the volcanic ash topsoils intact, leaving a remnant litter layer reduced first-year erosion 72 percent on 15 percent gradient skid trails, and 84 percent on 45 percent gradient skid trails (p. 9).

For skid trails with the volcanic ash topsoil bladed away and the alluvial subsoils exposed, first-year erosion was reduced by placing slash on the skid trail. Erosion on the slash-treated 50 percent gradient skid trail was 98.5 percent less than on a 40 percent gradient skid trail without slash, and 94.7 percent less than on a 15 percent gradient skid trail without slash (p. 9).

Skid trails with exposed (no slash) alluvial subsoils had much higher erosion rates and slower recovery than skid trails on volcanic ash topsoils (p. 9).

Although water bar use was not a variable in this study, it was assumed that water bars would be used whenever topsoils or subsoils were exposed (p. 10).

See the General Erosion Research Summary for additional information.

BMP 36—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: water barring (first alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by water barring (BMP 30).

BMP 37—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: cross draining (second alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by cross draining (BMP 31).

BMP 38—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: outsloping (third alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by outsloping (BMP 32).

BMP 39—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: scarifying (fourth alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by scarifying (BMP 33).

BMP 40—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: seeding (fifth alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by seeding (BMP 34).

BMP 41—Rule 3.e.i. Keeping current, stabilize erosion-prone fire trails by: other suitable means (sixth alternative).

No references were found specific to fire trails; see Rule 3.e.i., stabilization of skid trails by other suitable means (BMP 35).

BMP 42—Rule 3.e.ii. Reshape landings as needed to facilitate drainage prior to fall and spring runoff.

No references were found.

BMP 43—Rule 3.e.ii. Within 1 year after harvesting is completed, stabilize all landings by establishing ground cover (first alternative).

No references were found specific to landings; see the General Erosion Research Summary regarding stability due to ground cover. See Clayton 1990, under BMP 44, stabilization of landings by some other means.

BMP 44—Rule 3.e.ii. Within 1 year after harvesting is completed, stabilize all landings by: some other means (second alternative).

Clayton 1990, Silver Creek, Boise National Forest—The landing tested in this study was compacted (to a statistically significant degree assumed to be detrimental to productivity); standard rock rippers did not successfully reduce subsoil compaction. The author recommended that other implements such as the winged subsoiler be tested (p. 7).

Rule 3.f. Treatment of Waste Materials

Seventeen BMP's (45 through 61) were evaluated. Practices 45 through 47 comprise the general rule 3.f.: "All debris, overburden, and other waste material associated with harvesting shall be left or placed in such a manner as to prevent their entry by erosion, high water, or other means into streams." The remaining BMP's deal with five general topics:

- Felling, bucking, and limbing trees such that trees and tree parts fall away from Class I streams (BMP's 48 through 50);
- Removing slash and debris that falls into streams (BMP's 51, 52, 54, 55);
- Placement or treatment of material removed from streams (BMP's 53, 56, 57);
- Placement of waste material from construction or maintenance of landings, skid trails, and fire trails (BMP's 58 through 60);
- Placement of logging operation waste such as crankcase oil, filters, grease, and oil containers (BMP 61).

No research was found that addressed these topics in any depth. Only one study was considered relevant. Megahan and others (1995) found some evidence that removing logging slash from streams by hand may have released sediments stored behind natural channel obstructions.

The reader is also referred to Rule 4.c.ii., clearing road construction debris from drainage ways (BMP 115). King (1981, p. 63) concluded that normal slash clearing operations associated with road construction activities have minimal effects on stream sedimentation.

Research Results by Best Management Practice

BMP 45—Rule 3.f. Leave or place all debris associated with harvesting in such a manner as to prevent entry by erosion, high water, or other means into streams.

No references were found.

BMP 46—Rule 3.f. Leave or place all overburden associated with harvesting in such a manner as to prevent entry by erosion, high water, or other means into streams.

No references were found.

BMP 47—Rule 3.f. Leave or place all other waste material associated with harvesting in such a manner as to prevent entry by erosion, high water, or other means into streams.

No references were found.

BMP 48—Rule 3.f.i. Wherever possible, fell trees in such a manner that the tree or any part thereof will fall away from any Class I streams.

No references were found.

BMP 49—Rule 3.f.i. Wherever possible, buck trees in such a manner that the tree or any part thereof will fall away from any Class I streams.

No references were found.

BMP 50—Rule 3.f.i. Wherever possible, limb trees in such a manner that the tree or any part thereof will fall away from any Class I streams.

No references were found.

BMP 51—Rule 3.f.i. Continuously remove slash that enters Class I streams as a result of harvesting operations.

Megahan and others 1995, Silver Creek Study Area, Boise National Forest—In a paired watershed study of the effects of helicopter logging and broadcast burning, logging slash that fell into streams was removed by hand after the logging was completed.

The year following logging was the only year (of 7 years analyzed) that the unlogged watershed had more sediment stored behind channel obstructions. (There was no statistically significant difference between the two watersheds in channel sediment storage behind obstructions in any of the years before or after logging.) The authors hypothesized that slash removal may have disturbed some natural channel obstructions in the logged watershed.

See Rule 4.c.ii., clearing road construction debris from drainage ways (BMP 115).

BMP 52—Rule 3.f.i. Continuously remove other debris that enters Class I streams as a result of harvesting operations whenever there is a potential for stream blockage or if the stream has the ability for transporting such debris.

No references were found.

BMP 53—Rule 3.f.i. Place removed material 5 feet slope distance above the ordinary high water mark.

No references were found.

BMP 54—Rule 3.f.ii. Immediately after skidding remove slash that enters Class II streams whenever there is a potential for stream blockage or if the stream has the ability for transporting such debris.

Megahan and others 1995—See summary under BMP 51.

BMP 55—Rule 3.f.ii. Immediately after skidding remove other debris that enters Class II streams whenever there is a potential for stream blockage or if the stream has the ability for transporting such debris.

No references were found.

BMP 56—Rule 3.f.ii. Place removed material above the high water mark (first alternative).

No references were found.

BMP 57—Rule 3.f.ii. Otherwise treat (removed material) as prescribed by the department (second alternative).

No references were found.

BMP 58—Rule 3.f.iii. Deposit waste material from construction or maintenance of landings in geologically stable locations outside of the appropriate stream protection zone.

No references were found. See the General Erosion Research Summary regarding geologically stable locations.

BMP 59—Rule 3.f.iii. Deposit waste material from construction or maintenance of skid trails in geologically stable locations outside of the appropriate stream protection zone.

No references were found. See the General Erosion Research summary regarding geologically stable locations.

BMP 60—Rule 3.f.iii. Deposit waste material from construction or maintenance of fire trails in geologically stable locations outside of the appropriate stream protection zone.

No references were found. See the General Erosion Research Summary regarding geologically stable locations.

BMP 61—Rule 3.f.iv. Place waste resulting from logging operations (such as crankcase oil, filters, grease, and oil containers) outside of Class I and Class II stream protection zones.

No references were found.

Rule 3.g. Stream Protection

Twenty BMP's (62 through 81) were evaluated. Practice 62 is the general rule 3.g.: "During and after forest practice operations, protect streambeds and streamside vegetation to maintain water quality."

The remaining BMP's address four main topics:

- Stream crossings during skidding (BMP's 63 through 68);
- Cable yarding within the stream protection zone (BMP's 69 and 70);
- Vegetation management in Class I stream protection zones (BMP's 71 through 80);
- Soil protection in Class II stream protection zones (BMP 81).

Two references were found regarding stream crossings. In a paired watershed study near Pierce, Bachmann (1958, pp. 23, 34-35) found that skidding logs across the creek increased turbidities and stream blockages due to damming by slash and debris. Turbidities were 100 parts per million when logs were being skidded across the stream. Measured pretreatment turbidities on the same stream were less than 7 parts per million; on the control watershed they were less than 6 parts per million throughout the 3-year study period. Near Idaho City, Haupt and Kidd (1965, p. 668) observed sedimentation effects downstream from skid trail stream crossings.

No research was found on cable yarding within stream protection zones.

Only one study was found that actually compared water quality in logged areas with and without streamside buffer strips. In the Priest River Experimental Forest, Snyder (1973) compared physical and chemical properties upstream and downstream of areas that had been clearcut and that had the slash burned. For paired sampling stations with buffer strips, the only parameters with significant increases between the upstream and downstream stations were electrical conductivity, bicarbonate, sulfate, calcium, and magnesium. For paired sampling stations without buffer strips, all of those parameters showed significant differences; in addition, pH, turbidity, suspended solids, and potassium showed significant differences. Parameters showing no significant differences included chloride, nitrate, and sodium. Buffer strips may reduce suspended solids by blocking the movement of sediment and confining the flow of water to existing stable channels (pp. 64-65).

Clayton and Kennedy (1985, p. 1047) found minimal losses of nutrients in solution and in sediments for the first 4 years after clearcut logging and slash burning in the Silver Creek Study Area. Buffer strips were credited as one factor limiting movement of large amounts of nutrients mobilized by slash burning and decay, and for limiting sediment delivery to streams. In a companion study on the same watershed, Megahan and others (1995) found that total annual sediment yields were increased an average of 97 percent for 10 years after treatment. About 94 percent of the increased sediment yield was attributed to accelerated surface erosion (resulting primarily from broadcast burning) on the cutting units; a maximum of 6 percent was attributed to a mass erosion site on the cutting units. The sediment from the mass erosion site was delivered directly to the stream. Sediment delivery ratios could not be ascertained from the available data.

Based on their analyses of slope stability in the Idaho Batholith, Gray and Megahan (1981, pp. 20-21) recommended leaving buffer zones of undisturbed vegetation along all streams during clearcut logging operations. Several studies reported in the General Erosion Research Summary show the importance of vegetation in soil stabilization. See the road buffer strip rules (BMP's 86 through 88).

Research Results by Best Management Practice

BMP 62—Rule 3.g. During and after forest practice operations, protect streambeds and streamside vegetation to maintain water quality and aquatic habitat.

See more specific rules in 3.g.i., 3.g.ii., 3.g.iii., and 3.g.iv. (BMP's 63 through 81).

BMP 63—Rule 3.g.i. Avoid tracked or wheeled skidding in or through streams.

Bachmann 1958, Crystal and Silver Creeks near Pierce, Gold and Simmons Creeks near Avery—Skidding of logs across Crystal Creek increased turbidities and stream blockages due to slash and debris dams (p. 23). Turbidities were 100 parts per million when logs were being skidded across the stream. Measured pretreatment turbidities on the same stream were less than 7 parts per million; on the control watershed they were less than 6 parts per million throughout the 3-year study period (pp. 34-35).

Haupt and Kidd 1965, Boise Basin Experimental Forest near Idaho City—In this study, logs were skidded across streams only when it was impractical to do otherwise (p. 665). There were 58 skid trail channel crossings in the 16 logged watersheds (p. 666). Following use, skid trails were seeded, and cross ditched or covered with slash (p. 665). Although no quantitative data were reported, it was noted that the only sediment found in streams due to skidding was in areas immediately downstream of the skid trail crossings (p. 668).

BMP 64—Rule 3.g.i. Install adequate temporary structures to carry streamflow when streams must be crossed.

No references were found.

BMP 65—Rule 3.g.i. Cross a stream at right angles to its channel if at all possible.

No references were found.

BMP 66—Rule 3.g.i. Comply with the Stream Channel Protection Act when constructing hydraulic structures in streams.

No references were found.

BMP 67—Rule 3.g.i. Remove all temporary crossings immediately after use.

No references were found.

BMP 68—Rule 3.g.i. Water bar the ends of skid trails near channel crossings where applicable.

No references were found specific to water bars on the ends of skid trails near channel crossings; see Rule 3.e.i., water bar rule (BMP 30) for general information on the effectiveness of water bars on skid trails.

BMP 69—Rule 3.g.ii. Minimize streambank vegetation disturbance when cable yarding is necessary across or inside stream protection zones.

No specific references were found. See the General Erosion Research Summary for information on vegetation's effectiveness in stabilizing soil.

BMP 70—Rule 3.g.ii. Minimize channel disturbance when cable yarding is necessary across or inside stream protection zones.

No references were found.

BMP 71—Rule 3.g.iii. Provide the large organic debris (LOD), shading, soil stabilization, wildlife cover and water filtering effects of vegetation along Class I streams.

All the references found on the effectiveness of buffer strips between cutting units and streams are cited below. They do not distinguish between Class I and Class II streams.

See Rule 4.b.i., buffer strips below roads (BMP's 86 through 88) and the General Erosion Research Summary for information on vegetation's effectiveness in stabilizing soil.

Snyder 1973, Benton Creek, Ida Creek, and Canyon Creek, Priest River Experimental Forest—Water was sampled for various physical and chemical properties at stations upstream and downstream from areas that had been clearcut logged and had the slash burned. Buffer strips of undisturbed vegetation were 200 feet wide on Benton and Ida Creeks, and 100 feet wide on Canyon Creek (pp. 7, 9, 11).

For paired sampling stations with buffer strips, the only parameters with significant increases between the upstream and downstream stations were electrical conductivity, bicarbonate, sulfate, calcium, and magnesium. For paired sampling stations without buffer strips, all those parameters again showed significant differences; in addition, pH, turbidity, suspended solids, and potassium showed significant differences. Parameters showing no significant difference included chloride, nitrate, and sodium.

Buffer strips may reduce suspended solids by blocking the movement of sediment and confining the flow of water to existing stable channels (pp. 64-65).

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River Drainage, Boise National Forest—Several analyses evaluated the contributions of forest vegetation to slope stability through various mechanisms. The authors recommended leaving buffer zones of trees above and below haul roads, and leaving buffer zones of undisturbed vegetation along all streams during clearcut logging operations (pp. 20-21).

Clayton and Kennedy 1985, Silver Creek Study Area, Boise National Forest—A paired watershed approach was used to evaluate changes in nutrient budgets of six elements (potassium, calcium, magnesium, sulfur, phosphorus, and nitrogen) following clearcut logging, helicopter yarding, and broadcast burning of slash. Buffer strip widths averaged 15 meters for first- and second-order channels, and 30 meters for the third-order main channel (pp. 1042-1043). Nitrate-nitrogen in streamwater increased about 10 times for the 4 years after logging; no other treatment effects were apparent in the stream solution chemistry (pp. 1045-1046). There were small but significant changes in stream sediment nutrient transport for all elements the third year following logging (p. 1046).

Nutrient losses in solution and in sediments were characterized as "minimally accelerated" (p. 1047). Buffer strips were credited as one factor limiting movement of large amounts of nutrients mobilized by slash burning and decay, and limiting the delivery of sediment to streams (p. 1047).

Megahan 1987, and Megahan and others 1995, Silver Creek Study Area, Boise National Forest—In a paired watershed study, the treated watershed was helicopter logged; slash was broadcast burned. Buffer strips averaging 25 meters wide were left between cutting units and perennial streams. Vegetation within the buffer strips was undisturbed, except that trees expected to die before the next timber harvest were removed.

Total annual sediment yields at the watershed mouth were increased an average of 97 percent (or a total of 114 tonnes) for 10 years after treatment. Streamflow analyses and studies conducted in the channels indicated that accelerated channel erosion was not responsible for the increased sediment yields. Rather, about 94 percent of the increased sediment yield was attributed to accelerated surface erosion (resulting primarily from broadcast burning) on the cutting units; a maximum of 6 percent was attributed to a mass erosion site on the cutting units. The sediment from the mass erosion site (about 7 tonnes) was delivered directly to the stream. Sediment delivery ratios could not be ascertained from the available data.

BMP 72—Rule 3.g.iii.(a). Leave hardwood trees wherever they afford shade over a stream or maintain the integrity of the soil near a stream (Class I).

No specific references were found. See Rule 3.g.iii., general buffer strip rule (BMP 71), and the General Erosion Research Summary.

BMP 73—Rule 3.g.iii.(a). Leave shrubs wherever they afford shade over a stream or maintain the integrity of the soil near a stream (Class I).

No specific references were found. See Rule 3.g.iii., general buffer strip rule (BMP 71), and the General Erosion Research Summary.

BMP 74—Rule 3.g.iii.(a). Leave grasses wherever they afford shade over a stream or maintain the integrity of the soil near a stream (Class I).

No specific references were found. See Rule 3.g.iii., general buffer strip rule (BMP 71), and the General Erosion Research Summary.

BMP 75—Rule 3.g.iii.(a). Leave rocks wherever they afford shade over a stream or maintain the integrity of the soil near a stream (Class I).

No specific references were found. See Rule 3.g.iii., general buffer strip rule (BMP 71), and the General Erosion Research Summary.

BMP 76—Rule 3.g.iii.(b). Leave 75 percent of the current shade over the stream (Class I).

No references were found.

BMP 77—Rule 3.g.iii.(c). Carefully log the mature timber from the (Class I) stream protection zone in such a way that shading and filtering effects are not destroyed.

No specific references were found. See Rule 3.g.iii., general buffer strip rule (BMP 71), and the General Erosion Research Summary.

BMP 78—Rule 3.g.iii.(d). and (e). Leave standing trees, including conifers, hardwoods, and snags (snags within given limitations), within 50 feet of the ordinary high water mark on each side of all Class I streams in the given minimum numbers per 1,000 feet of stream (first alternative).

No references were found.

BMP 79—Rule 3.g.iii.(f). Request a site-specific riparian management prescription as an alternative to the standing tree and shade requirements for Class I streams (second alternative).

No references were found.

BMP 80—Rule 3.g.iii.(g). Where the opposite side of the stream does not currently meet the given minimum standing tree requirements, consider a site-specific riparian prescription that meets the large organic debris needs of the stream (Class I).

No references were found.

BMP 81—Rule 3.g.iv. Provide soil stabilization and water filtering effects along Class II streams by leaving undisturbed soils in widths sufficient to prevent washing of sediment into Class I streams. In no case shall this width be less than 5 feet slope distance above the ordinary high water mark on each side of the stream.

See rule 3.g.iii., Class I buffer zones (BMP 71); rule 4.b.i., buffer strips below roads (BMP's 86 through 88); and the General Erosion Research Summary.

Rule 3.h. Maintenance of Productivity and Related Values

Three BMP's (82 through 84) were evaluated. These comprise the "wet areas" Rule 3.h.iii.: "When conducting operations along bogs, swamps, wet meadows, springs, seeps, wet draws, or other sources where the presence of water is indicated, protect soil and vegetation from disturbance that would cause adverse effects on water quality, quantity, and wildlife habitat. Consider leaving buffer strips." Other rules in 3.h. deal with wildlife and esthetic values and were not within the scope of the BMP project.

No research was found specifically addressing the wet area BMP's. See the General Erosion Research Summary, the timber harvest buffer strip rule (BMP 71), and the road buffer strip rules (BMP's 86 through 88).

Research Results by Best Management Practice

BMP 82—Rule 3.h.iii. When conducting operations along lakes, bogs, swamps, wet meadows, springs, seeps or other sources where the presence of water is indicated, protect soil from disturbance that would cause adverse effects on water quality, water quantity, wildlife habitat, and aquatic habitat.

No specific references were found. See the General Erosion Research Summary; Rule 3.g.iii., timber harvest buffer strips (BMP 71); and Rule 4.b.i., road buffer strips (BMP's 86 through 88).

BMP 83—Rule 3.h.iii. When conducting operations along lakes, bogs, swamps, wet meadows, springs, seeps or other sources where the presence of water is indicated, protect vegetation from disturbance that would cause adverse effects on water quality, water quantity, wildlife habitat, and aquatic habitat.

No specific references were found. See the General Erosion Research Summary; Rule 3.g.iii., timber harvest buffer strips (BMP 71); and Rule 4.b.i., road buffer strips (BMP's 86 through 88).

BMP 84—Rule 3.h.iii. When conducting operations along lakes, bogs, swamps, wet meadows, springs, seeps or other sources where the presence of water is indicated, consider leaving buffer strips.

No specific references were found. See Rule 3.g.iii., timber harvest buffer strips (BMP 71); and Rule 4.b.i., road buffer strips (BMP's 86 through 88).

Rule 4. Road Construction and Maintenance

Rule 4.b. Road Specifications and Plans

Twenty-four BMP's (85 through 108) were evaluated. Five major themes regarding road planning are:

- Minimum disturbance, including minimum road standard, minimum cut and fill volumes, and minimum road width (BMP's 85, 89 through 91, 93, 94);
- Road buffer strips: minimum road construction within the stream protection zone, and providing for vegetation between roads and streams (BMP's 86 through 88);
- Disposition of excavated material (BMP's 92, 95, 96);
- Road drainage, culverts, and stream crossings (BMP's 97 through 107);
- Reuse and reconstruction of existing roads (BMP 108).

Minimum Disturbance

Several studies have implications for roadcut volumes. Two studies (Burroughs and others 1972, p. 11; Megahan 1972, p. 355) showed that even relatively low roadcuts can intercept significant amounts of surface and subsurface snowmelt runoff, disturbing slope hydrology and creating potential road drainage and erosion problems.

In the Horse Creek Study Area, ditch aggradation increased as cut height increased (Tennyson and others 1981, pp. 55, 70). Also, as roadcut area or height increased, cutslope erosion volumes increased (King 1981, pp. 83, 101; Tennyson and others 1981, pp. 16, 21). However, in the Silver Creek Study Area, cut height was not a significant variable in predicting surface erosion (Boise State University, Department of Geology and Geophysics 1984, pp. 16, 30, 31).

The Silver Creek study correlated cutslope gradient with cutslope erosion (p. 18). The same conclusion was reached in a study of long-term (45-year) cutslope erosion in the same area (Megahan and others 1983, pp. 24, 25). The authors recommended constructing cutslopes at lower gradients on gentle terrain and using terraced slopes on steeper terrain (p. 27). On the other hand, Gonsior and Gardner (1971, p. 33) recommended building cuts "as steep as possible consistent with subsurface conditions." Megahan and Bohn (1989, p. 508) noted that progressive mass failures can occur at relatively low slope gradients under certain conditions of subsurface flow; hazards are increased if timber has been harvested above the roadcut (p. 509). Jensen and Finn (1966, p. 8) suggested that on glacial moraine lands, roadcuts should be laid back to 1.5:1 or 67 percent, to prevent round glacier-packed boulders from rolling out of the roadcut.

Several reports of fillslope erosion in the Horse Creek Study Area showed that erosion increased with fill height (Cook and King 1983, pp. 3-4; King 1979, pp. 5, 6; King 1981, p. 83; Tennyson and others 1981, pp. 13, 15, 16). In the Gospel Hump area, fill length and vertical fill height (along with time since construction) were the best predictors of fill erosion volumes, and were also highly correlated with sediment transport distances (Carlton and others 1982, pp. 31, 32, 39). In the Idaho Batholith, Megahan (1974a, p. 11) reported greater tree growth in the upper fourth of fills averaging 200 feet in length. The study showed that the planted trees significantly reduced surface erosion (pp. 13-14); other research studies indicated that the trees should also reduce the risk of mass erosion (pp. 2-3).

Several studies in the Idaho Batholith addressed the importance of fillslope gradient with respect to surface and mass erosion. Jensen and Cole (1965, p. 13) reported that the major cause of fill failures in the South Fork Salmon River drainage was the location of roads on steep slopes when the natural angle of repose of the fill material (67 percent or 1.5:1) was exceeded or approached too closely to allow a margin of safety. They recommended that fills be built at an angle of 50 percent or 2:1 (p. 13); if fill lengths are limited, this puts constraints on road siting based on hill slope gradients (p. 14). Investigations of slope failures (Gonsior and Gardner 1971, pp. 30-31) revealed that slope steepness was a major factor in all road-associated failures. Based on laboratory tests, they recommended that "no unretained slopes should be allowed in excess of 35 degrees, or 70 percent, on roadfills." It was also noted that steep slopes were more prone to surface erosion of fine particles. However, for plot studies in the Silver Creek Study Area, fillslope gradient was not a statistically significant predictor of sediment yield over the range of the data set, 34 to 41 degrees (Megahan and others 1991, pp. 54-56; Megahan and others 1992).

Hartsog and Gonsior (1973, p. 6) reported that roadfills designed for 67 percent, but constructed at the angle of repose (70-80 percent), showed sloughing and settlement cracks and eroded during a high-intensity rainstorm. Megahan (1974a, p. 1) noted that investigations by the Payette National Forest concluded that fills constructed at angles exceeding the natural angle of repose could not be stabilized by grass seeding (p. 1).

Some studies looked at combinations of cut, fill, and tread. Based on investigations of mass failures in the Idaho Batholith, Gonsior and Gardner (1971, p. 33) recommended sacrificing road alignment to avoid deep cuts and fills. Similarly, Hartsog and Gonsior (1973, p. 21) recommended minimizing heights of cuts and fills, and tread width to reduce road erosion. Ketcheson and Megahan (1990, pp. 4-5) found that sediment flow volume and travel distances increased as total source areas (including cut, fill, tread, and undisturbed slopes contributing sediment) increased. Earlier investigations by Haupt (1959b, pp. 330-331) suggested that fill length, but not cut height or road width, predicted flow distance. Packer (1967, pp. 12-13) did not find cut, fill, or tread dimension variables to be significant predictors of sediment flow distance.

The relative importance of cut, fill, and tread as sources of surface and mass erosion were discussed in several reports (Arnold and Lundeen 1968, p. 117; Burroughs and King 1989, p. 16; Jensen and Cole 1965, p. 11; Jensen and Finn 1966, p. 70; King 1981, p. 106; Megahan and Kidd 1972a, pp. 10-11; Megahan and others 1979, p. 131). See Research Results by Best Management Practice, BMP 85, Road Construction and Maintenance, for details.

Three studies specifically addressed road standard. Megahan and others (1979, p. 131) found that as road standard increased, so did the frequency of landslides. They attributed the increased landslides to the increased volume of material excavated. King (1981, p. 76) noted that regardless of the intended road standard, the area disturbed was often a function of topographical constraints and location of the road within the landscape. In the Horse Creek Study Area, road standard was not as important as sideslope characteristics in predicting sediment transport distance (King 1979, p. 9).

Road Buffer Strips

Twelve studies reported on sediment movement below roads; some of these tried to identify the variables controlling the distance of sediment movement. Variables that seem to be important include: obstructions on the slope, road drainage features, fillslope characteristics, and site characteristics. Time since construction and weather also play a role.

Several of these studies noted the importance of obstructions (including vegetation) on the slope below the road. For example, Haupt (1959b, pp. 330-331) found that the "slope obstruction index," related to the downhill spacing of obstructions, was the variable most highly related to transport distance. Major slope obstructions included in the index were "standing trees, down snags, logging slash and fallen branches greater than 3 inches in diameter, rock outcrops, clumps of brush higher than 2 feet, tree stumps, hummocks, and natural depressions." Grass and low brush between major obstructions were also considered when computing the index.

Packer and Christensen (1964, pp. 7, 9) noted that slope obstructions vary in their ability to retard sediment flow. The following were listed in order of decreasing effectiveness:

(1) Depressions made by pushed-over or wind-thrown trees, or a wavy ground surface;
(2) Logs thicker than 4 inches;
(3) Rocks more than four inches wide at ground surface;
(4) Trees and stumps;
(5) Slash and brush;
(6) Grass, weeds, and shrubs.

Using this classification for 720 sites in Idaho and Montana, Packer (1967, pp. 12-13) reported that obstruction spacing, and the interaction of obstruction spacing and obstruction type, were the variables most highly related to sediment transport; initial obstruction distance was also significant (ranking fifth among the variables).

In the Gospel Hump area, the obstruction index was a statistically significant variable in explaining sediment transport distances (Carlton and others 1982, pp. 38-39). In this case, the obstruction index was a measure of the relative efficiency of obstructions in blocking the flow of sediment (pp. 17, 82). Ketcheson and Megahan (1990, p. 11) noted that obstructions can deflect or stop sediment flow if they are large, in contact with the ground, and oriented perpendicular to the fall line of the slope. Small stems are generally ineffective in deflecting or stopping sediment flow. Based on Ketcheson and Megahan's study, Burton (n.d., p. 2) reported a strong correlation between sediment storage behind obstructions and lengths of sediment flow in the Silver Creek Study Area. Length of obstructions was one of four variables in an equation predicting sediment flow travel distances (p. 3).

Filter windrows are a special kind of obstruction purposely placed at the toe of the fill. Research in the Horse Creek Study Area (Burroughs and King 1989, p. 9; Cook and King 1983, p. 4; King 1979, pp. 9-10; Tennyson and others 1981, p. 41) has shown slash filter windrows to reduce movement of sediment below fillslopes. The length of windrows constructed at five stream crossings totalled 1,190 feet. Only seven sediment flows were observed below the windrowed fills in the 3-year study period; three of these had sediment delivery to the stream. Breaching of windrows usually occurred as a result of slumping when snowmelt saturated the fill. Average transport distance for sediment flows was 3.8 feet below windrows. For fills without filter windrows, the average transport distance was 41.4 feet for flows originating in slumps, and 24.2 feet for flows originating in areas that had not slumped (Cook and King 1983, pp. 2-4).

Road drainage features are another important factor influencing sediment movement below roads. Haupt (1959b) looked at various road design and site factors as predictors of sediment flow distance below logging roads that had been "put to bed" (standard logging road closure techniques that include cross ditching and removal of temporary culverts) (pp. 329-330). This analysis showed that the cross ditch interval squared, and the product of cross ditch interval and road gradient, ranked second and fourth among the variables tested (pp. 330-331). A similar exercise by Packer (1967, pp. 12-13) showed that of 24 watershed and road characteristics tested as predictors of sediment movement downslope from logging roads, cross drain spacing was fourth in importance.

When roads were being constructed in the Silver Creek Study Area, sediment flows associated with berm drains or cross drains (relief culverts) had greater volumes and traveled farther than those originating on fillslopes (Megahan and others 1986, pp. 35-36). The same pattern held in the 4 years after construction (Ketcheson and Megahan 1990, p. 3). Probability distributions were developed for sediment flow volume and length by source, including relief culverts, berm drains, and rock drains (pp. 9-10, 13-16).

Similarly, in the Horse Creek Study Area, sediment flows influenced by relief culverts (where the source gully was below or adjacent to a culvert) tended to travel farther than other flows (Tennyson and others 1981, pp. 41-42). Presence or absence of runoff from the road surface was an important variable in predicting sediment flow distance (p. 44). Burroughs and King (1989, p. 10) developed frequency distributions of sediment transport distance for flows influenced by relief culverts, and for travelway runoff compared with no travelway runoff, based on the Horse Creek data.

Fillslope characteristics that appear to influence the distance of sediment transport include fillslope length or height, cover density, gullying or slumping, bulk density, and parent material. The relation between sediment transport and fillslope length or vertical height was discussed in the previous section on minimum disturbance. See Haupt 1959b, pp. 331-332; Tennyson and others 1981, pp. 43-44; Carlton and others 1982, pp. 38-39. Fillslope cover density was the seventh most important variable in Packer's (1967, pp. 13, 15-16) analysis of sediment transport distance. Several reports from the Horse Creek Study Area indicate that sediment transport distances increase as source gully volume increases (King 1979, p. 6; Tennyson and others 1981, pp. 43-44); slumped material is transported greater distances than unslumped material (Burroughs and King 1989, p. 9; Cook and King 1983, p. 4; Tennyson and others 1981, p. 41). Bulk density of fill material was a significant predictor of transport distance in the Gospel Hump area (Carlton and others 1982, pp. 38-40). Parent material will be discussed in the next section.

Site characteristics potentially important to sediment transport include the parent material and the sideslope gradient. For example, in Packer's analyses (1967, pp. 12-14), the third most important predictor of sediment transport distance was percentage by weight of undisturbed slope soil particles and water-stable aggregates greater than 2 mm in diameter. The following soil groups were listed in order of decreasing percentages (and increasing sediment movement): basalt, andesite, glacial silt, hard sediments, granite, and loess. In the Gospel Hump area, sediment flows originating from nongranitic fill materials were predicted to travel about 5 feet farther than those from granitic fill materials (Carlton and others 1982, p. 47).

In Haupt's study (1959b, p. 331) the lower sideslope gradient was not significant, which was attributed to the confounding effect of slope obstructions. However, in the Horse Creek Study Area, King (1979, pp. 8, 9) reported that as slope gradient increased, larger volumes of sediment were transported greater distances in the first year after construction. In the same area, Tennyson and others (1981, pp. 43-44) found slope gradient to be a significant predictor of sediment transport distance in the second year following construction. Reports from the Silver Creek Study Area also indicate that gradient influenced sediment transport distances (Burton n.d., p. 3; Ketcheson and Megahan 1990, p. 5). Sideslope gradient was one of four independent variables in the equation predicting transport (Burton n.d., p. 3).

Despite this research on sediment transport below roads, transport is still difficult to predict accurately due to the numerous interacting variables (Burroughs and King 1989, p. 8). While individual variables may test highly significant, the predictive multiple regression equations generally have low *r*-squared values, indicating they predict only a small fraction of the variability (Carlton and others 1982, pp. 39-40; Packer 1967, p. 13; Tennyson and others 1981, pp. 41, 44). Another approach is to report the distribution of sediment flows in time and space. Several such reports are available (Burroughs and King 1989, pp. 9-11; Carlton and others 1982, p. 38; Haupt and Kidd 1965, p. 668; Ketcheson and Megahan 1990, pp. 3, 9-10, 12-16; King 1979, pp. 6, 8, 9; Megahan 1991, p. 146; Megahan and others 1986, pp. 35-36; Tennyson and others 1981, pp. 39, 41, 42, 44); see Research Results by Best Management Practice for BMP's 86 through 88. This approach may provide useful information, but the unique circumstances of site conditions, road design, and weather that produced a given data set are unlikely to be duplicated elsewhere.

Buffer strips may be desirable not only for limiting sediment delivery from roads to streams, but also for reducing mass and surface erosion. For example, Gonsior and Gardner (1971, pp. 31-32) recommended leaving trees below roadfills because tree roots enhance soil stability by mechanical reinforcement and by removing moisture. Similarly, Gray and Megahan

(1981, pp. 20-21) suggested leaving trees above and below haul roads, based on their analyses of the contributions of forest vegetation to slope stability through various mechanisms. See the General Erosion Research Summary for more information on the influence of vegetation on surface and mass erosion.

Disposition of Excavated Material

Only one reference was found. Clayton and Arnold (1972, p. 16) suggested borrowing fill for placement in areas of very well weathered granitic rock, to promote fillslope stability. See the General Erosion Research Summary for information on geologically stable sites.

Road Drainage, Culverts, Stream Crossings

Four reports were found that compared the relative merits of insloping with outsloping (Burroughs and King 1989, p. 16; Gonsior and Gardner 1971, p. 33; Hartsog and Gonsior 1973, p. 20; Haupt and others 1963, p. 8). All concluded that insloping was generally preferable; outsloping requires special attention to road design, erosion control measures, and maintenance.

Dips, water bars, and cross drains were discussed in four references. Haupt and others (1963, pp. 6-7) noted that earthen cross drains spaced 30 to 90 feet apart generated erosion on both insloped and outsloped road sections during severe storms. If earthen cross drains are used, they recommended draining them on the outcurve (p. 8). Based on their analyses of the contributions of vegetation to slope stability, Gray and Megahan (1981, p. 21) recommended that road cross drainage structures should drain onto undisturbed vegetation.

Both Haupt (1959b, pp. 330-331) and Packer (1967, pp. 13-14) found spacing of cross drainage structures to be a significant variable with respect to sediment flow distance. Haupt (1959a) used his regression equation to develop tables for use in road design, construction, and abandonment. Various tables can be used to estimate the buffer strip widths, cross ditch interval, or slope obstruction index to minimize sediment delivery to streams for a wide range of road and site characteristics (pp. 9-20). Similarly, Packer (1967) developed a table (pp. 16-17) using his regression equation (p. 12) to define buffer strip width given obstruction spacing and obstruction types with adjustments for soil type, cross drain spacing, distance to initial obstruction, fillslope cover density, the percent of erosion prevention, and so forth. A table with the same information also appears in the publication by Packer and Christensen (1964, pp. 15-17).

Packer (1967) also investigated cross drain spacing needed to prevent formation of road surface rills exceeding 1 inch in depth. Significant variables, in order of importance, were: road surface stability, road surface grade, topographic position, aspect, and upper slope steepness (pp. 6-7). The regression equation (p. 6) was used to develop a table (p. 11) that gives cross drain spacings by road grade and soil type with adjustments for topographic position, aspect, slope steepness, and the percent of cases in which 1-inch rill formation is prevented. This table is found on page 14 of the report by Packer and Christensen (1964), who also provided guidelines for installation of some cross drainage structures (pp. 33-36).

Tennyson and others (1981) measured ditch aggradation and degradation on a newly constructed road. During snowmelt periods, ditches generally degraded (deepened); distance between culverts and road gradient were significantly and positively correlated with degradation (pp. 55, 70). During the first snowmelt period, ditches on roads with gradients of 6 to 9 percent degraded an average of 0.122 feet (p. 55). During summer, aggradation (filling) was more common; aggradation was significantly and positively correlated with cutslope height (p. 70). In general, deposition was observed in the first 100 feet of the ditch; erosion increased with increasing distances along the ditch (pp. 57-58).

Experiments with simulated rainfall on the Nez Perce National Forest indicate that degradation of an unprotected ditch might produce more sediment than an unprotected road tread on roads with low volumes of traffic (Burroughs and King 1989, p. 14). In these experiments (Burroughs and others 1983b, p. 14), the ratio of sediment yields were:

(unrocked ditch + untreated cutslope) :
(rocked ditch + untreated cutslope) = 2.29.

Burroughs and King (1989, pp. 13-14) outline procedures for designing roadside ditch riprap for forest roads.

In the Silver Creek Study Area, results from preconstruction seismic and resistivity surveys were used to accurately predict the necessary drainage design and to plan underdrain installation on a new collector road (Clayton 1983, p. 5).

Several studies reported on sediment movement below relief culverts (Burroughs and King 1989; Ketcheson and Megahan 1990; Megahan and others 1986; Tennyson and others 1981). These studies were summarized under "Road Buffer Strips" (pp. 30-31).

Gray and Megahan (1981, p. 21) recommended leaving undisturbed vegetation in areas large enough to accommodate road drainage (water spreading areas) based on their analyses of slope stability. Megahan and others (1979, p. 131) studied the relationship between culverts and landslide frequency, volume, and delivery. Twenty-seven percent of road-associated slides originated on roadfills without culverts, compared to 7 percent on fills with culverts. Thirty-one percent of the volume from road-associated slides originated on fills without culverts, compared to 21 percent on fills with culverts. Fifty-one percent of the road-associated slide material delivered to streams originated on fills without culverts, compared to 16 percent that originated on fills with culverts.

Several reports addressed culvert installation and stream crossings. In northern Idaho, Bachmann (1958, pp. 22, 35, 37) observed temporarily increased turbidity and a sediment deposit associated with culvert installation. Increases in sedimentation and turbidity were noted at crossings of some small tributaries (p. 25). Over the course of the study, increases in turbidity were noted only during rain, snowmelt, and direct channel disturbances; sediment sources were predominantly at stream crossings (pp. 35, 37). Although turbidity sampling was not adequate to define average or maximum values (p. 37), turbidity differences were apparent above and below road crossings (p. 35).

In the Horse Creek Study Area, sediment increases were observed when roads were pioneered, temporary culverts were placed, slash was cleared from the right-of-way, and culverts were permanently installed (King 1981, pp. 62, 67). Routing the streamflow around the construction site when culverts were permanently installed, "dewatering," reduced sedimentation (King and Gonsior 1980, p. 9). Shortly after construction, sediment concentrations at the crossings returned to preconstruction levels, except during rainstorms. Then, sediment loads were about 100 to 1,000 times higher than normal (p. 11). During the first snowmelt period following construction, considerable sediment was generated at crossings (p. 11). The following summer (1 year after construction), sediment loads during storms were about 10 times higher than normal (p. 15).

Three references provided recommendations for culvert design and installation. Based on their observations of storm damage to logging roads, Haupt and others (1963, p. 8) recommended that culverts placed in major ravines be laid on the original grade so that they drain into the original channel rather than on the fill of the incurve. Hartsog and Gonsior (1973) recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10). They also discussed proper bedding of culverts and compaction of backfill material (p. 12). Gonsior and Gardner (1971, p. 12) measured low soil permeabilities in their investigations of slope failures, noting that decreasing permeability over time must be accounted for in culvert planning. They stressed the need to evaluate surface and subsurface flow conditions when locating and designing roads (p. 33). No references were found on planning culvert installation to provide for fish passage.

Hartsog and Gonsior (1973, p. 21) stressed the need for careful planning to control sediment from the road's cutslope and ditch. They recommended routing water down the road surface rather than along the toe of the cutslope. They also recommended providing for sediment filtering or settling before runoff leaves the road surface, or for discharging drainage far enough away from streams to provide for water infiltration and clarification.

Reconstruction of Existing Roads

No references specifically addressed reconstruction versus new road construction; however, numerous references show that total erosion or erosion on various components of the road prism decreases over time (ranging from the first season to the first 3 years). Megahan (1974b) has the largest data set spanning the longest time. He has dealt most directly with the trend of erosion. He developed a negative exponential equation showing surface erosion on severely disturbed granitic soils over time. By far the greatest percentage of erosion occurs in the first and second years after construction (p. 12). In the first year, erosion rates are about 1,000 times greater than on undisturbed lands (p. 12). Additional disturbances result in new cycles of surface erosion (p. 13).

Research Results by Best Management Practice

BMP 85—Rule 4.b. Plan each road to the minimum use standards adapted to the terrain and soil materials to minimize disturbances and damage to forest productivity, water quality, and wildlife habitat.

To avoid repetition, and to consider interactions among variables, this rule will be combined with the rules for minimum road width, minimum cut volumes, and minimum fill volumes (BMP's 89, 90, and 91). Each reference will indicate whether it pertains to road standard, road width, roadcut volume, roadfill volume, or some combination. See the General Erosion Research Summary regarding the requirement "adapted to the terrain and soil materials."

It is intuitively clear that minimizing the area disturbed in cuts, tread and ditch, or fill should reduce erosion. However, other factors such as cut and fill angles must also be considered.

Haupt 1959a,b, width, cut, fill, Little Owl Creek watershed, Boise River basin—Haupt (1959b), tested seven variables, including road width, roadcut height, and embankment slope length as predictors of sediment flow distance below logging haul roads that had been "put to bed" (standard logging road closure techniques that include cross ditching and removal of temporary culverts). Multiple regression analysis showed that the "slope obstruction index" was the most highly related, followed by the cross ditch interval squared, the embankment slope length, and the product of cross ditch interval and road gradient (pp. 330-331). In the regression equation, an increase of 1 foot of embankment slope length increases sediment flow distance by about 3.5 feet (p. 332). The range of embankment slope lengths used to develop the equation was 1 to 32 feet (p. 331). Haupt (1959a) cautioned against extrapolating beyond a 20-foot embankment slope length (p. 6).

Jensen and Cole 1965, fill, South Fork Salmon River drainage—A survey of mass erosion during an April 1965 rain and snowmelt event showed that 77.5 percent of the landslides originated on roadfills (p. 11). The major cause of fill failures was the location of roads on steep slopes such that the natural angle of repose of the fill material (67 percent or 1.5:1) was exceeded or approached too closely to allow a margin of safety (p. 13). They recommended building fills at an angle of 50 percent or 2:1 (p. 13). If fills are to be less than 100 feet long, this recommendation would limit construction to slopes with gradients less than or equal to 45 percent. If fills are to be less than 50 feet long, this recommendation would limit construction to slopes with gradients less than or equal to 38 percent (p. 14).

Jensen and Finn 1966, width, cut, fill, Zena Creek Logging Study Area, Payette National Forest—Rates are given for average yearly surface erosion from cut, tread or ditch, and fill. Information is provided for four landtypes: strongly glaciated granitic soils, periglacial (ice action mainly on site) granitic soils, river terrace lands, and decomposed granitic soils. For strongly glaciated granitic soils and river terrace lands, the values for all road prism components are 0.1 inch surface erosion per year. For periglacial granitic soils, the cut value is 0.2 inch, the tread and ditch and the fill values are 0.1 inch. For the decomposed granitic soils, the cut value is 1.0 inch, the tread and ditch value is 0.1 inch, and the fill value is 0.5 inch (p. 70).

The authors recommend minimizing roadcutting operations on decomposed granitic soils and on the face of river terraces (pp. 4, 8, 28, 32, 62). On decomposed granitic soils, road construction on slopes over 45 percent requires slope stabilization measures (p. 8). On glacial moraine lands, roadcuts should be reduced in steepness to 1.5:1 or 67 percent, to prevent round glacier-packed boulders from rolling out of the roadcut (p. 8).

Packer 1967, width, cut, fill, 720 sites in Idaho and Montana—Twenty-five road and watershed characteristics were tested as predictors of sediment movement distance downslope from road cross drains (pp. 4-5). Among these variables were cut height and gradient, fill length and gradient, and road width; however, none of these appeared in the final multiple-regression equation (p. 12).

Arnold and Lundeen 1968, width, cut, fill, South Fork Salmon River drainage—A survey of erosion on the roads producing the highest sediment levels indicated that 65 percent of sediment originated from fillslopes, 10 percent from cutslopes and ditches, 21 percent from maintenance wasting of cutslope material, and 4 percent from road surfaces (p. 117).

Gonsior and Gardner 1971, cut, fill, Zena Creek drainage, Payette National Forest—Investigations of slope failures revealed that slope steepness was a major factor in all road-associated failures. Based on laboratory tests, the authors recommended that "no unretained slopes should be allowed in excess of 35 degrees, or 70 percent, on roadfills." They also noted that steep slopes were more prone to surface erosion of fine particles (pp. 30-31).

The authors recommended building cutslopes, "as steep as possible consistent with subsurface conditions," and sacrificing alignment to avoid deep fills or cuts (p. 33).

Burroughs and others 1972, cut, near Lolo Pass at the Idaho-Montana border—Substantial volumes of water were intercepted at roadcuts with an average height of 36 inches (p. 3) during the snowmelt season in the deep snow zone (p. 11). Subsurface seepage averaged 58 percent of the total; the remainder occurred as overland flow (p. 10). In the central Idaho Batholith, such overland flow from snowmelt is seldom observed (p. 12). See Megahan (1972) for information on a similar study in the Idaho Batholith.

Megahan 1972, cut, Pine Creek, Boise National Forest—Subsurface flow interception was measured along roadcuts deep enough to expose bedrock (average soil depth was about 31 inches) in first order watersheds (p. 351). Subsurface flow was intercepted only during the spring snowmelt period (p. 353). The volume of flow intercepted was about 7.3 times greater than the estimated snowmelt runoff from the road area alone (p. 355). About 35 percent of the total subsurface flow was intercepted by the roadcut (p. 355). More subsurface flow was intercepted in drainage bottoms, but flow was not limited to those areas (p. 353).

See Burroughs and others (1972) for information on a similar study.

Megahan and Kidd 1972a, width, cut, fill, Zena Creek Study Area, Payette National Forest—Time trends for erosion on logging roads were discussed. High initial erosion rates were largely due to fillslope erosion; these high rates could be avoided by fill stabilization methods (p. 11). Continued accelerated road erosion rates were expected due to erosion of weathered granitic bedrock on the road tread and steep cutslopes (p. 10).

Hartsog and Gonsior 1973, width, cut, fill, South Fork Salmon River drainage, Payette National Forest—During the construction period and the early period of use, an engineering research team evaluated a road designed to minimize watershed impacts. Fills that had been designed for 67 percent, but constructed at the angle of repose (70 to 80 percent), showed sloughing and settlement cracks, and also eroded during a high-intensity rainstorm (p. 6). The primary recommendation for future projects was to minimize heights of cuts and fills, and widths of tread, sacrificing road alignment as necessary (p. 21).

Megahan 1974a, fill, Deadwood River drainage, Boise National Forest—Previous investigations by the Payette National Forest concluded that fills constructed at angles exceeding the natural angle of repose could not be stabilized by grass seeding (p. 1). This study investigated roadfill surface erosion control from various combinations of tree planting, tree seeding, fertilizing, mulching, and netting (pp. 5-6).

Planted trees significantly reduced surface erosion (pp. 13-14); other studies indicated trees should also reduce mass erosion (pp. 2-3). Trees grew faster in the upper fourth of the fillslope than in lower parts (the fill length averaged 200 feet). Megahan suggested the increased growth might be due to deeper soils and greater moisture nearer the road (p. 11).

King 1979, standard, fill, Horse Creek Study Area, Nez Perce National Forest—In the first year after construction, fill erosion volumes (per 100 feet of road length) increased as fillslope height increased (pp. 5, 6). See King (1981) for an analysis of this trend, including additional years of data.

A survey of rills and gullies found that the largest average volumes occurred on fillslopes from 20 to 30 feet high (p. 6). However, the largest gullies, which had the greatest transport distances, were not related to the height of the fill, but to improper drainage from the road surface (pp. 6, 11). Transport distances of material eroded from fillslopes depended more on sideslope characteristics below the fills than on the road standard (p. 9).

See King (1981), Tennyson and others (1981), and Cook and King (1983) for additional information.

Megahan and others 1979, standard, cut, fill, Clearwater National Forest and Middle Fork of the Payette River drainage, Boise National Forest—In a survey of mass erosion, 66 percent of road-associated slides originated on roadcuts, 27 percent on roadfills without culverts, and 7 percent on fills with culverts. Forty-seven percent of the volume originated on cuts, 31 percent originated on fills without culverts, and 21 percent originated on fills with culverts. However, 33 percent of the slide material delivered to streams originated on cuts, 51 percent originated on fills without culverts, and 16 percent originated on fills with culverts (p. 131).

When roads were built to lower standards, landslide frequency decreased, presumably because less excavation was required. The average number of slides per kilometer of road was 2.2 for arterial, 1.2 for collector, 0.6 for service, and 0.2 for temporary or terminal roads (p. 131).

King 1981, standard, cut, fill, Horse Creek Study Area, Nez Perce National Forest—Length of fillslopes was controlled largely by topographical constraints; roads designed to minimize cuts and fills (Standard II) always disturbed a greater area than the higher standard roads (Standard I) due to steeper sideslopes in the areas where Standard II roads were constructed. Both road standards had fill gradients of 1.5:1 (p. 76).

Road erosion data were evaluated for 1 to 3 years after construction. As the area of roadfill increased, winter erosion increased (p. 81). As roadcut area increased, total cutslope erosion increased (p. 101).

For both cuts and fills, erosion volumes per mile of road length increased as cut or fill height increased (pp. 83, 101). The study compared erosion when the cut or fill height was the shortest (category 1) to taller heights (categories 2, 3, and 4). Height category 1 was 0 to 10 feet; category 2 was 10 to 20 feet; category 3 was 20 to 30 feet; and category 4 was greater than 30 feet for both cuts and fills (pp. 78, 96). For fills on all study roads, erosion was 6.9 times greater for category 2, 17.0 times greater for category 3, and 19.5 times greater for category 4 (p. 83). On average, for cuts on all study roads, erosion was 5.5 times greater for category 2, 7.5 times greater for category 3, and 10.0 times greater for category 4 (p. 101).

For each height category, cut erosion was greater than fill erosion; the difference increased as height increased (p. 106). Percent differences between cut and fill erosion were 7.0, 121.2, and 179.9 for categories 1, 2, and 3, respectively. The average percent difference was 98.4.

See King (1979), Tennyson and others (1981), and Cook and King (1983) for additional information.

Tennyson and others 1981, cut, fill, Horse Creek Study Area, Nez Perce National Forest—For one study road analyzed, erosion volume per mile of road length increased as both cut and fill heights increased (pp. 13, 15, 16, 21). See King (1981) for the average increase by height category for all study roads (the figures are similar in both reports). Aggradation of the ditch increased significantly as cutslope height increased (pp. 55, 70).

See King (1979, 1981), and Cook and King (1983) for additional information.

Carlton and others 1982, fill, Gospel Hump management areas, Nez Perce National Forest—Fillslope erosion on newly constructed (1978 and 1979) logging roads was measured in 1980 and 1981, using both bordered erosion plots and rill surveys. All fillslopes were fertilized, seeded, and hydromulched (p. 13).

The rill survey data, considered more representative of the actual fillslope erosion volumes (pp. 38, 45), were used to develop predictive multiple regression equations (p. 32). Fill length and vertical fill height, along with time since construction, were the variables found to be the best predictors of fillslope erosion volumes. Slope length and vertical height of the fillslope were also highly correlated with sediment transport distances (p. 39).

Cook and King 1983, fill, Horse Creek Study Area, Nez Perce National Forest—For 3 years after road construction, eroded material was collected in troughs below windrowed and nonwindrowed fillslopes in two height classes: 0 to 10 feet (class 1) and 10 to 20 feet (class 2) (p. 3). All fillslopes had a 1.5:1 slope and were seeded, hydromulched, and fertilized (p. 2). Erosion volumes (in cubic feet per 100 feet of road length) were greater on class 2 fillslopes for both windrowed and nonwindrowed fills (pp. 3-4):

	Erosion volumes	
	Windrowed	**Nonwindrowed**
	(ft^3 / 100 ft road length)	
Class 1	0.325	35.85
Class 2	0.650	64.30

See King (1979, 1981), and Tennyson and others (1981) for additional information.

Megahan and others 1983, cut, Silver Creek Study Area, Boise National Forest—Long-term (45-year) cutslope erosion was positively correlated with original cutslope gradient (pp. 24, 25). The authors recommended constructing cutslopes at lower gradients on gentle terrain and using terraced slopes on steeper terrain (p. 27).

Boise State University, Department of Geology and Geophysics 1984, cut, fill, Silver Creek Study Area, Boise National Forest—Sediment collected in troughs below cutslopes and at the bottom of bordered fillslope plots was measured for a period of 3 years after road construction.

No discernible trend was apparent between cutslope source area above the trough (which depended on cutslope length) and erosion volume (pp. 16, 30, 31). Cutslope lengths ranged from 10 feet to more than 50 feet (p. 7). Cutslope sediment yield increased as cutslope gradient increased, based on a subsample of 40 cutslope plots with a range in gradient of 0.95:1 to 1.51:1 (p. 18).

See Megahan and others (1991, 1992) for results of the fill plot data analysis.

Burroughs and King 1989, cut, fill, Horse Creek Study Area, Nez Perce National Forest—Sediment entering the stream from the ditch system (representing erosion of the cut, ditch, and 28 percent of the road surface) and that entering from the fillslope side (representing erosion of the fillslope and 72 percent of the road surface) was monitored for 4 years after construction (p. 16). At the study site, the cut and fill had no erosion control treatment, and the road was unsurfaced (p. 15).

Partitioning of the sediment between the two entry sites reversed over time. The first year, 20 percent entered from the ditch, and 80 percent from the fillslope side. By the fourth year, 83 percent entered from the ditch, and 17 percent from the fillslope side. This reversal was attributed to stabilization over time of the fillslope due to surface armoring and revegetation (p. 16).

Megahan and Bohn 1989, cut, Silver Creek Study Area, Boise National Forest—A progressive mass failure (sapping failure) originating in a road cutslope was attributed to cutslope construction at a gradient of 34 degrees. The angle of friction for the soil material type is about 33 degrees; failures can occur at half the angle of friction when seepage is parallel to the slope (p. 508). Mass erosion hazards of this type in the cutslope are increased if timber is harvested above the roadcut (p. 509).

Ketcheson and Megahan 1990, width, cut, fill, Silver Creek Study Area, Boise National Forest—Sediment flows were inventoried from various sources including fills, cross drains (relief culverts), berm drains, rock drains, and landings. Sediment flow length and volume increased as the area contributing runoff and sediment to each of the sources increased (pp. 4-5).

Megahan and others 1991, fill, Silver Creek Study Area, Boise National Forest—Sediment from bordered fillslope erosion plots was measured for 3 years after road construction (p. 54). Fillslope gradient was not a statistically significant predictor of sediment yield over the range of the data set, 34 to 41 degrees (pp. 54-56).

See Boise State University, Department of Geology and Geophysics (1984) and Megahan and others (1992) for additional information.

Megahan and others 1992, fill, Silver Creek Study Area, Boise National Forest—Sediment from bordered fillslope erosion plots was measured for 3 years after road construction. No significant difference in fillslope erosion was found between design slopes of 34 degrees (1.33:1), and 37 degrees (1.5:1). Also, no significant interactions were found between the two design slopes and the three fillslope construction practices (sidecast, layer placement, and controlled compaction). The results were the same when the actual fillslope gradients, rather than the design gradients, were used.

See Boise State University, Department of Geology and Geophysics (1984), Megahan and others (1991). See the General Erosion Research Summary.

BMP 86—Rule 4.b.i. Plan transportation networks to minimize road construction within stream protection zones.

BMP 87—Rule 4.b.i. Design to leave areas of vegetation between roads and streams (first alternative).

BMP 88—Rule 4.b.i. Design to reestablish areas of vegetation between roads and streams (second alternative).

Since research with implications for one of these three rules generally has implications for the others, they will be considered together here. No references were found specific to reestablishing vegetation between roads and streams. See the General Erosion Research Summary regarding the value of vegetation in reducing surface and mass erosion.

Bachmann 1958, Silver and Crystal Creeks, near Pierce—This study investigated the effects of logging and logging road construction on selected physical, chemical, and biological features of northern Idaho trout streams (pp. 2-3), using a paired-watershed approach (p. 9). Measured predisturbance (1955 and 1956) turbidities ranged from 0.25 to 2.10 parts per million in Silver Creek, and from 0.6 to 6.9 parts per million in Crystal Creek (p. 34).

In the Crystal Creek drainage, which had road construction activity in 1956 and 1957, a vegetated buffer strip (width unspecified) was left between the road and stream, except at stream crossings. Roadfills were not treated at stream crossings (pp. 21-22). Temporarily increased turbidity (90 parts per million) and a sediment deposit were associated with culvert installation (pp. 22, 35, 37). Increases in sedimentation and turbidity were noted at crossings of some small tributaries (p. 25). However, most of the material that eroded from the road prism was not delivered to the stream due to the distance between the road and the stream (p. 25). Increases in turbidity were noted only during rainfall, snowmelt, and direct channel disturbances; sediment sources were predominantly at stream crossings (pp. 35, 37). Although turbidity sampling was inadequate to define average or maximum values (p. 37), turbidity was different above and below road crossings, and between the roaded and unroaded watersheds (p. 35).

Haupt 1959a,b, Little Owl Creek watershed, Boise River basin—Haupt (1959b) looked at various road design and site factors as predictors of sediment flow distance below logging roads that had been "put to bed" (standard logging road closure techniques that include cross ditching and removal of temporary culverts) (pp. 329-330). Multiple regression analysis showed that the "slope obstruction index" was the variable most highly related to transport distance, followed by cross ditch interval squared, embankment slope length, and the product of cross ditch interval and road gradient (pp. 330-331). Slope obstructions included in the index were "standing trees, down snags, logging slash, and fallen branches greater than 3 inches in diameter, rock outcrops, clumps of brush higher than 2 feet, tree stumps, hummocks, and natural depressions" (p. 330). The lower sideslope gradient was not significant, because of the confounding effect of slope obstructions (p. 331). The regression equation can be used to predict necessary buffer strip widths under various conditions (p. 332).

Haupt (1959a) used the regression equation to develop tables for road design, construction, and abandonment. Various tables can be used to estimate the buffer strip widths, cross ditch interval, or slope obstruction index necessary to minimize sediment delivery to streams under a wide range of road and site characteristics (pp. 9-20).

Packer and Christensen 1964, 720 sites in Idaho and Montana—This publication is a field guide for controlling logging road sediment, primarily through the control of cross drain spacing and buffer strip widths. It is based on the research reported in Packer (1967) and on field experience.

The authors noted that slope obstructions vary in their ability to retard sediment flow. In order of decreasing effectiveness they include (pp. 7, 9):

(1) Depressions made by pushed-over or wind-thrown trees, or a wavy ground surface
(2) Logs thicker than 4 inches
(3) Rocks more than 4 inches wide at ground surface
(4) Trees and stumps
(5) Slash and brush
(6) Grass, weeds, and shrubs.

A table was developed giving buffer strip widths required to prevent sediment delivery in 83 percent of cases, based on obstruction spacing and obstruction type (p. 16). Adjustment factors are provided to allow for soil group, cross drain spacing, distance to first obstruction, fillslope cover density, and 97 percent prevention of sediment delivery (pp. 15-17).

Obstruction storage capacity tended to be exceeded by the fourth or fifth year after road construction. Buffer strips could be narrower if drainage was diverted toward other obstructions or if new obstructions were provided when the road was 3 years old (p. 11).

See Packer (1967) for additional information.

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—An attempt was made to minimize erosion associated with logging and logging road construction in 1953 and 1954 by using "good logging practices" including careful road location, a minimum number of stream crossings, 10-foot minimum buffer strips between roads and streams whenever possible, and seeding and harrowing of roads following use (p. 665).

Sediment flow distances were measured from 1953 to 1957 and in 1960 (p. 667). Of 104 sediment flows below haul roads, 50 percent were less than 5 feet long, 80 percent were less than 10 feet long, and all were less than 30 feet long (p. 668). Severe storms in 1956 lengthened flows; only six lengthened after 1956 (p. 668).

More than 20 percent of the flows reached stream channels (p. 668). The width of the buffer strip was apparently critical in preventing delivery. The 8-foot mean width of buffer strips through which sediment flows reached a channel was significantly different from the 30-foot mean width of buffer strips that contained flows within their boundaries (p. 669).

Jensen and Finn 1966, Zena Creek Study Area, Payette National Forest—Based on their hydrological analysis, the authors recommended limiting road construction on stream-cut decomposed granite lands to the ridgetops. If roads are built elsewhere, cuts and fills should be fully stabilized and intercepted subsurface flow should be routed in a manner least disruptive to the natural patterns (pp. 8, 32).

Packer 1967, 720 sites in Idaho and Montana, representing six major soil groups—Twenty-four watershed and road characteristics were tested as predictors of sediment movement downslope from logging roads. The significant variables, in order of importance, were obstruction spacing, the interaction of obstruction type and obstruction spacing, undisturbed slope stability, cross drain spacing, initial obstruction distance, age of road, and fillslope cover density (pp. 12-13). A multiple regression equation was developed (p. 12), and was also represented in a tabular form (pp. 16-17). This is essentially the same table as that in Packer and Christensen (1964, pp. 15-17), except that distances are measured from the shoulder of the road rather than from the centerline.

See Packer and Christensen (1964) for additional information.

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—The authors conducted field and laboratory investigations of slope failures and soil properties. They recommended leaving barriers of live trees below all road fillslopes so their roots could enhance soil stability through mechanical reinforcement and by depleting soil moisture (pp. 31-32).

Megahan and Kidd 1972a, Zena Creek Study Area, Payette National Forest—A barrier of logs and debris substantially lowered sediment yields from logging roads by intercepting sediment flows on one of three study watersheds (pp. 5-6).

King 1979, Horse Creek Study Area, Nez Perce National Forest—Travel distances for sediment flows resulting from rill and gully erosion of roadfills were evaluated for 1 year following road construction. Gullies with the largest volumes of erosion had greater transport distances (p. 6). The relationship between percent of eroded volume deposited and distance below the road was curvilinear (pp. 6, 8, 9). The majority of the material was transported less than 20 feet in the first year (pp. 6, 8, 9). As slope gradient increased, larger volumes were transported greater distances (pp. 8, 9). Sediment transport distance appeared to be related more to sideslope characteristics than to the road design standard (p. 9).

Filter windrows were very effective in limiting material available for transport (0.22 cubic feet of eroded material per 100 feet of road length) in the first year after road construction (pp. 9-10).

See Tennyson and others (1981), Cook and King (1983), and Burroughs and King (1989) for followup reports.

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River drainage, Boise National Forest—Analyses evaluated the contributions of forest vegetation to slope stability through various mechanisms. The authors recommended leaving buffer zones of trees above and below haul roads, and leaving buffer zones of undisturbed vegetation along all streams during clearcut logging operations (pp. 20-21).

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—Travel distances for sediment flows resulting from rill and gully erosion of roadfills were evaluated for 2 years after road construction.

Transport distances were variable (pp. 39, 41, 42). The maximum flow distance was 150 feet (p. 41). Flows influenced by relief culverts (those with the source gully below or adjacent to culverts) tended to travel farther than other flows (p. 41). Flows originating from rills and gullies in slumps had greater average travel distances than those originating in fill areas that did not slump, 41.4 feet compared to 24.2 feet (p. 41). No sediment was transported beyond fills with slash filter windrows the first year after construction; average sediment flow distance below windrows was 3.8 feet the second year after construction (p. 41). The average transport distance for all flows was 11.2 feet at the beginning of the study, and 26.3 feet 2 years later (p. 42). For flows not associated with windrows or relief culverts, an average of 73 percent of the material was deposited within 50 feet of the roadfill 2 years after construction (p. 44).

Regression models of sediment transport had low predictive values, probably due to the omission of important variables such as obstruction information. Gully volume was the most important predictor of travel distance for both the first and second year; the presence or absence of runoff from the road surface was also important. For the second year, fillslope height and sideslope gradient were also significant (pp. 41, 43, 44).

See King (1979), Cook and King (1983), and Burroughs and King (1989) for additional information.

Carlton and others 1982, Gospel Hump Management Areas, Nez Perce National Forest—Rill, gully, and slump surveys (pp. 16-17) were conducted from spring 1980 through fall 1981 on fills of roads constructed in 1978 and 1979. All fillslopes had been fertilized, seeded, and hydromulched (p. 13).

Excluding sediment flows influenced by culverts, average downslope transport of sediment below the fills was 8.4 feet, varying from 0 to 53 feet (p. 38). Several variables were significantly correlated with transport distance, including fillslope length and vertical height, sediment volume, bulk density, and obstruction index (pp. 38-39). Regression equations developed from the data had low *r*-squared values, probably because data were not available for other important variables such as site-specific precipitation and runoff (pp. 39-40). Sediment flows originating from nongranitic fill materials were predicted to travel about 5 feet farther than those from granitic fill materials (p. 47).

See Burroughs and King (1989) for additional information.

Cook and King 1983, Horse Creek Study Area, Nez Perce National Forest—Sediment transport below fills was evaluated for 3 years after road construction. All fills were 1.5:1 slopes, and were seeded, hydromulched, and fertilized. Some had slash filter windrows constructed at the toe of the fill. Windrows at five stream crossings were a total of 1,190 feet long (pp. 2-4).

Only seven sediment flows were observed below the windrowed fills in the 3-year study period; three of these delivered sediment to the stream. Windrows usually breached as a result of slumping when snowmelt saturated the fill (p. 4). Average transport distance for sediment flows was 3.8 feet below windrows. For fills without windrows, the average transport distance was 41.4 feet for flows originating in slumps, and 24.2 feet for flows originating in areas of the fill that had not slumped (p. 4).

Most of this information is also presented in Tennyson and others (1981). First year results are presented in King (1979). See Burroughs and King (1989) for additional information.

Megahan and others 1986, Silver Creek Study Area, Boise National Forest—A sediment budget was developed for material eroded from roads during construction. All measurements were made within a year of the completion of construction. About 85 percent of the eroded material was stored on slopes, 8 percent was stored in the stream channels, and 7 percent was delivered to the mouths of the watersheds (p. 38).

The volume and transport distance of sediment flows below the road were measured. Sediment flows associated with berm drains or cross drains (relief culverts) had greater volumes and travel distances than those originating on fillslopes. For sediment flows originating on fillslopes, the average flow traveled 6 meters; the longest traveled 64 meters, with 94 percent traveling less than 15 meters. The average sediment flow originating from drainage structures traveled 32 meters, the longest traveled 118 meters, with 39 percent transported less than 15 meters. Volumes of sediment flows averaged 0.3 cubic meters for flows from fills compared to 4.7 cubic meters from drainage structures (pp. 35-36).

See Ketcheson and Megahan (1990), Megahan (1991), and Burton (n.d.) for additional information.

Burroughs and King 1989, Horse Creek Study Area and Gospel Hump management areas, Nez Perce National Forest—For most midslope forest roads, only fillslopes close to stream channels are likely to deliver sediment to the streams. However, predicting sediment flow distance is difficult due to the numerous interacting variables (p. 8).

Most of the results are in the summaries above for King (1979), Tennyson and others (1981), Carlton and others (1982), and Cook and King (1983).

Fillslope sediment flow travel distance data from one road were summarized for 2 years after construction at Horse Creek (p. 9). They showed the influence of slash filter windrows, travelway drainage, slumping, and culverts. For flows not influenced by any of these, the average transport distance was 25.8 feet and the maximum was 86 feet. Windrows reduced travel distances to an average of 3.8 feet with a maximum of 33 feet. The average travel distances were increased to 58.8 feet by travelway drainage (maximum 85 feet), to 72.8 feet by culvert flow (maximum 125 feet), and to 80.4 feet by slumping (maximum 106 feet). Figures showing cumulative frequency of travel distance can be used to plan buffer strips in areas similar to Horse Creek (gneiss and schist parent materials with 30 to 40 percent sideslope gradients) (pp. 10-11).

The distance sediment flowed was not strongly correlated with road gradient, length of the road segment draining into the culvert, or sideslope gradient for Horse Creek sediment flows related to relief culverts.

Over half of the sediment flows below relief culverts were transported more than 75 feet (p. 10).

A plot of sediment transport distance at Gospel Hump showed that travelway drainage increased average distances, while greater densities of obstructions reduced them (p. 9).

See King (1979), Tennyson and others (1981), Carlton and others (1982), and Cook and King (1983) for additional information.

Ketcheson and Megahan 1990, Silver Creek Study Area, Boise National Forest—Volumes and lengths of sediment flows below roads were measured for 4 years after road construction. Statistics are given (p. 3) for length and volume by source (fills with and without cull logs placed at toe, cross drains (relief culverts), berm drains, rock drains, and landings). Sediment flows from cross drains (relief culverts) had the greatest average volume (819.5 cubic feet) and length (248 feet), and also contained 63 percent of the total sediment flow volume (pp. 3, 5). Sediment flows from fills traveled an average of 20 feet (p. 3), with average volumes of around 24 cubic feet. Flows associated with berm drains averaged 66 feet long (205.1 cubic feet) and those associated with rock drains averaged 39 feet long (24.5 cubic feet). Differences in sediment flow volume and length among the sources were related to the sizes of the contributing source areas, including both the road prism and undisturbed watershed (pp. 3, 5).

Probability distributions were developed for sediment flow volume and length by source. Maximum travel distances were less than 200 feet for all sources except cross drains, for which the maximums ranged to 900 feet. Sediment flows from cross drains have a 0.15 probability of traveling farther than 300 feet. Volume distributions were similar to those for distance. The probability distributions can be used to plan buffer strip widths based on road drainage structures (pp. 9, 10, 12-16).

Sediment flow volumes decrease rapidly within the first 75 feet of travel. Gradient and obstructions influence sediment volume distribution for those portions of flows more than 75 feet below roads (pp. 5, 7, 8). Obstructions can deflect or stop sediment flow if they are large, in good contact with the ground, and oriented perpendicular to the slope. Small stems are generally ineffective in this regard (p. 11).

See Megahan and others (1986), Megahan (1991), and Burton (n.d.) for additional information.

Megahan 1991, Silver Creek Study Area, Boise National Forest—For sediment flows originating from roadfills, more than 95 percent of the total volume was within 20 meters of the toe of the fill 4 years after construction (p. 146).

See Megahan and others (1986), Ketcheson and Megahan (1990), Burton (n.d.) for additional information.

Burton, n.d., Silver Creek Study Area, Boise National Forest. Unpublished data attributed to Megahan—Sediment storage behind obstructions was strongly correlated with lengths of sediment flow (p. 2). An equation relating sediment flow travel distance to sideslope gradient, source area, total length of obstructions, and total volume of onsite sediment was derived (p. 3).

See Megahan and others (1986), Ketcheson and Megahan (1990), Megahan (1991). See also the General Erosion Research Summary.

BMP 89—Rule 4.b.ii. Plan to minimize road width to that which will safely accommodate the anticipated use.

See Rule 4.b. (BMP 85), references marked "width."

BMP 90—Rule 4.b.ii. Minimize cut volumes by designing the road alignment to fit the natural terrain features as closely as possible.

See Rule 4.b. (BMP 85), references marked "cut."

BMP 91—Rule 4.b.ii. Minimize fill volumes by designing the road alignment to fit the natural terrain features as closely as possible.

See Rule 4.b. (BMP 85), references marked "fill."

BMP 92—Rule 4.b.ii. Use as much of the excavated material as practical in fill sections.

Clayton and Arnold 1972, Idaho Batholith—Areas of the most highly weathered granitic rock class (class 7) are prone to landslides. The authors suggest that stability would be enhanced by borrowing fill from areas with other rock-weathering classes (p. 16).

BMP 93—Rule 4.b.ii. Plan minimum cuts, particularly near stream channels.

See Rule 4.b. (BMP 85), references marked "cut," and Rule 4.b.i., road buffer strips (BMP's 86 through 88).

BMP 94—Rule 4.b.ii. Plan minimum fills, particularly near stream channels.

See Rule 4.b. (BMP 85), references marked "fill," and Rule 4.b.i., road buffer strip rules (BMP's 86 through 88).

BMP 95—Rule 4.b.iii. Design embankments so that excavated material may be disposed of on geologically stable sites.

No specific references were found. See the General Erosion Research Summary for references regarding geologically stable sites.

BMP 96—Rule 4.b.iii. Design waste so that excavated material may be disposed of on geologically stable sites.

No specific references were found. See the General Erosion Research Summary for references regarding geologically stable sites.

BMP 97—Rule 4.b.iv. Plan roads to drain naturally by: outsloping (first alternative).

BMP 98—Rule 4.b.iv. Plan roads to drain naturally by: insloping (second alternative).

These two BMP's will be reviewed together.

Haupt and others 1963, Zena Creek Logging Study Area, Payette National Forest—Following three long-duration, low-intensity storms of unprecedented total rainfall (pp. 4-5), the authors visually evaluated erosion on insloped and outsloped sections of a newly constructed logging road. Both insloped and outsloped sections had earthen cross drains spaced 30 to 90 feet apart (p. 2). Shoulders and fills had been seeded and mulched with chopped hay and asphalt binder (p. 3).

Insloped sections had less erosion damage than outsloped sections. The outsloped sections had severe erosion of the roadbed, decreasing the usable width, while damage on the insloped sections was slight (pp. 6-7). The worst damage on outsloped sections occurred at the mouths of swales on incurves (p. 6). All earthen cross drain outlets were deeply eroded on the outsloped portions (p. 6). Cross drains also generated fill erosion on insloped sections (p. 7). Fill erosion, although widespread on both insloped and outsloped sections, was more severe on outsloped sections, especially on incurves (pp. 6-7). No cases were observed where sloughing on insloped sections interfered with inside drainage; this was attributed to the shallow soils on the roadcuts (p. 7)

Based on their observations, the authors recommended insloping, leading as much runoff as possible away from the long fill on the incurve (p. 8). They also recommended that if earthen cross drains are to be used, they should drain on the outcurve (p. 8).

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—Based on field and laboratory investigations of slope failures, the authors recommended insloping all fill sections and providing outside berms, unless adequate fillslope erosion control measures can be provided. Benched sections could be outsloped if natural vegetation or erosion control measures are adequate to prevent erosion (p. 33).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—An engineering research team evaluated a road designed to minimize watershed impacts, during the construction period and the early period of use. The road had been designed as an outsloped road, but did not function that way because trenches had been left by tractors and skidded logs, and because berms had been left along the edge of the road during grading (p. 13). The authors felt that outsloping would seldom function as designed due to runoff concentrated by wheels and slight differences in soil properties. They recommended outsloping only where surfaces are "relatively non-erodible," such as full-bench sections (p. 20).

They further noted that insloping can result in considerable sediment movement unless cutslopes and ditches are stabilized. They suggested that roads should be designed to carry water along the tread, and that provisions should be made to filter or settle out sediment before road runoff reaches streams (p. 21).

Burroughs and King 1989, Horse Creek Study Area, Nez Perce National Forest—The authors recommended insloping to the ditch or providing for uniform distribution of outslope drainage. Outsloped sections would require care during road maintenance to avoid creating berms and to maintain uniform drainage (p. 16).

BMP 99—Rule 4.b.iv. Plan roads to drain naturally by grade changes where possible.

No references were found.

BMP 100—Rule 4.b.iv. Plan dips on roads when necessary.

BMP 101—Rule 4.b.iv. Plan water bars on roads when necessary.

BMP 102—Rule 4.b.iv. Plan cross drainage on roads when necessary.

These three BMP's are considered together here.

Haupt 1959a,b, Little Owl Creek watershed of the Boise River Basin—Haupt (1959b) looked at various road design and site factors as predictors of sediment flow distance below logging roads that had been "put to bed" (standard logging road closure techniques that include cross ditching and removal of temporary culverts) (pp. 329-330). Multiple regression analysis showed that the "slope obstruction index" was the variable most highly related to transport distance, followed by cross ditch interval squared, embankment slope length, and the product of cross ditch interval and road gradient (pp. 330-331). The regression equation can predict necessary buffer strip widths under various conditions (p. 332).

Haupt (1959a) used the regression equation to develop tables for road design, construction, and abandonment. Various tables can be used to estimate the buffer strip widths, cross ditch interval, or slope obstruction index necessary to minimize sediment delivery to streams under a wide range of road and site characteristics (pp. 9-20).

Haupt and others 1963, Zena Creek Logging Study Area, Payette National Forest—Following three long-duration, low-intensity storms of unprecedented total rainfall (pp. 4-5), the authors visually evaluated erosion on insloped and outsloped road sections of a newly constructed logging road. Both insloped and outsloped sections had earthen cross drains spaced 30 to 90 feet apart (p. 2). Shoulders and fills had been seeded and mulched with chopped hay and asphalt binder (p. 3).

All earthen cross drain outlets were deeply eroded on the outsloped portions (p. 6). Cross drains also generated fill erosion on insloped sections. Cross drain outlets were the only site where surface drainage had overtopped the road on inslopes (p. 7). The authors recommended that if earthen cross drains are to be used, they should drain on the outcurve (p. 8).

Packer and Christensen 1964, 720 sites in Idaho and Montana—This publication is a field guide for controlling logging road sediment, primarily through the control of cross drain spacing and buffer strip widths. It is based on the research reported in Packer (1967) and field experience.

Logging road surfaces deteriorate rapidly when rill erosion exceeds 1 inch in depth. A table (pp. 13-15) gives cross drain spacing required to prevent 83 percent of cases of rill erosion deeper than 1 inch by road grade and soil group, with adjustment factors for slope position, exposure, sidehill slope gradient, and increased erosion prevention (97 percent).

Another table (p. 16) gives buffer strip widths (measured from the road centerline) required to prevent sediment delivery in 83 percent of cases, based on obstruction spacing and obstruction type. Adjustment factors are provided to allow for soil group, cross drain spacing, distance to first obstruction, fillslope cover density, and 97 percent prevention of sediment delivery (pp. 15-17).

Guides are provided for estimating some of the variables (pp. 17-22), and for installing devices to control erosion and sediment flow, including some cross drainage structures (pp. 33-40).

See Packer (1967) for additional information.

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—The authors evaluated efforts to minimize erosion associated with logging and logging road construction. "Good logging practices" included seeding, harrowing, and cross draining of roads following logging in 1953 and 1954 (p. 665). By 1958, the perennial grasses that had been seeded on the roadways were well established and erosion was negligible during the most intense storm (2.82 inches per hour for 10 minutes) of the 7-year study period (p. 668).

Packer 1967, 720 sites in Idaho and Montana, representing six major soil groups—Twenty-four watershed and road characteristics were tested as predictors of: (1) cross drain spacing needed to prevent road surface rills deeper than 1 inch, and (2) the distance of sediment movement downslope. Cross drainage structures included dips, cross ditches, and open-top culverts; these were not evaluated separately. For the analysis of cross drain spacing, significant variables, in their order of importance, were road surface stability, road surface grade, topographic position, aspect, and upper slope steepness (pp. 6-7). The regression equation (p. 6) was used to develop a table (p. 11) that gives cross drain spacings by road grade and soil type with adjustments for topographic position, aspect, slope steepness, and the percent of cases in which 1-inch rills are prevented. This is the same as the table (p. 14) in Packer and Christensen (1964).

Cross drain spacing was one of the significant variables in the prediction of sediment transport distance. A table (pp. 16-17) was developed using the regression equation (p. 12) to define buffer strip width given obstruction spacing and obstruction types with adjustments for soil type, cross drain spacing, distance to initial obstruction, fillslope cover density, the percent of erosion prevention, and so forth. (See the road buffer strip rule, Rule 4.b.i., BMP's 86 through 88). The authors suggest increasing buffer strip width by 1 foot for each 10-foot increase in cross drain spacing beyond 30 feet (p. 16). This is essentially the same table as in Packer and Christensen (1964, pp. 15-17), except that distances are measured from the road shoulder rather than from the road centerline.

See Packer and Christensen (1964) for additional information.

Megahan and Kidd1972a,b, Zena Creek Study Area, Payette National Forest—The authors studied erosion and sedimentation from logging and road construction. Roads built in October 1961 were seeded and water barred after logging was completed in November 1962. The average sedimentation rate in ephemeral drainages below roads for 4.8 years after logging was 51.0 tons per square mile per day. No data were collected for comparison on roads that were not seeded or water barred. Sedimentation rates on nearby undisturbed watersheds averaged 0.07 tons per square mile per day. A return to predisturbance levels was not expected due to continued roadcut and tread erosion.

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River drainage, Boise National Forest—Analyses evaluated the contributions of forest vegetation to slope stability through various mechanisms. The authors recommended that road cross drainage structures should drain onto undisturbed vegetation (p. 21).

BMP 103—Rule 4.b.v. Plan relief culverts and roadside ditches whenever reliance upon natural drainage would not protect the running surface, excavation, or embankment.

Megahan and others 1979, Clearwater National Forest and Middle Fork of the Payette River drainage, Boise National Forest—In a survey of mass erosion, 66 percent of road-associated slides originated on roadcuts, 27 percent originated on roadfills without culverts, and 7 percent originated on fills with culverts. Forty-seven percent of the erosion volume originated on roadcuts, 31 percent originated on fills without culverts, and 21 percent originated on fills with culverts. However, just 33 percent of the slide material delivered to streams originated on roadcuts, 51 percent originated on fills without culverts, and 16 percent originated on fills with culverts (p. 131).

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River drainage, Boise National Forest—Analyses evaluated the contributions of forest vegetation to slope stability through various mechanisms. The authors recommended leaving areas of undisturbed vegetation, water spreading areas, large enough to accommodate road drainage (p. 21).

Tennyson and others 1981, Horse Creek, Nez Perce National Forest—Ditch elevation was measured following road construction. During snowmelt periods, ditches generally degraded; the distance between culverts and the road gradient was significantly and positively correlated with degradation (pp. 55, 70). During the first snowmelt period, ditches on roads with gradients of 6 to 9 percent degraded an average of 0.122 feet (p. 55). During summer, aggradation (filling) was more common; aggradation was significantly and positively correlated with cutslope height (p. 70). In general, deposition was observed in the first 100 feet of the ditch; erosion increased with increasing distance (pp. 57-58).

Burroughs and others 1983b, Rainy Day Road, Nez Perce National Forest—Tests with simulated rainfall compared the sediment yield from the ditch plus the untreated cutslope for rocked and unrocked ditches. The ratio of sediment yields (p. 14) was:

(unrocked ditch + untreated cutslope) :
(rocked ditch + untreated cutslope) = 2.29

Clayton 1983, Silver Creek Study Area, Boise National Forest—Results from preconstruction seismic and resistivity surveys were used to accurately predict the necessary drainage design and to plan underdrain installation on a new collector road (p. 5).

Megahan and others 1986, Silver Creek Study Area, Boise National Forest—A sediment budget was developed for material eroded from roads during construction. In the fall of the year of construction, about 85 percent of the eroded material was stored on slopes (p. 38).

The authors measured the volume and transport distance of sediment flows below the road. Sediment flows associated with berm drains or cross drains (relief culverts) had greater volumes and travel distances than those originating on fillslopes. For sediment flows originating on fillslopes, the average travel distance was 6 meters, the maximum was 64 meters; 94 percent were transported less than 15 meters. For sediment flows originating from drainage structures, average travel distance was 32 meters, the maximum was 118 meters; 39 percent were transported less than 15 meters. Volumes of sediment flows averaged 0.3 cubic meters for flows from fills compared to 4.7 cubic meters for flows from drainage structures (pp. 35-36).

See Ketcheson and Megahan (1990) for a followup report.

Burroughs and King 1989, Horse Creek Study Area and Rainy Day Road, Nez Perce National Forest—Rill volumes and sediment flow transport distances were measured in the Horse Creek Study Area for 2 years after road construction. One of the longest average transport distances (72.8 feet) for sediment flows below road fillslopes resulted when rills were formed below relief culvert outflows or when sediment flows from rills combined with relief culvert flow paths (pp. 8-9).

Transport distances below relief culverts were not strongly correlated with the length of road contributing to the culvert, the road gradient, or the sideslope gradient (p. 10). A figure (p. 10) shows the cumulative frequency of sediment travel distances for flows influenced by relief culverts; this might apply to similar sites with gneiss and schist parent material and sideslope gradients of 30-40 percent (p. 11).

Procedures for designing roadside ditch riprap for forest roads are given (pp. 13-14). Experiments with simulated rainfall on the Rainy Day Road indicate that degradation of an unprotected ditch might produce more sediment than erosion from an unprotected road tread on roads with low volumes of traffic (p. 14).

See Tennyson and others (1981), and Burroughs and others (1983b) for additional information.

Ketcheson and Megahan 1990, Silver Creek Study Area, Boise National Forest—The authors measured volumes and lengths of sediment flows below roads for 4 years after road construction. Statistics give length and volume by source: fills with and without cull logs placed at toe, cross drains (relief culverts), berm drains, rock drains, and landings (p. 3). Sediment flows from cross drains (relief culverts) had the greatest average volume (819.5 cubic feet) and length (248 feet); they contained 63 percent of the total sediment flow volume (pp. 3, 5). The mean length of flows associated with berm drains was 66 feet (mean volume 205.1 cubic feet) compared to a mean length of 39 feet for rock drains (mean volume 24.5 cubic feet). Differences were related to the sizes of the contributing source areas, including both road prism and undisturbed watershed areas (pp. 3, 5).

Probability distributions were developed for sediment flow volume and length by source. Maximum travel distances were less than 200 feet for all sources except cross drains (relief culverts), for which the maximum ranged to 900 feet. For cross drains, the probability of travel distances exceeding 300 feet is 0.15. Volume distributions were similar to those for distance. The probability distributions can be used to plan the width of buffer strips based on road drainage structures (pp. 9, 10, 12-16).

See Megahan and others (1986) for additional information.

For general information on road drainage see the General Erosion Research Summary, especially Gonsior and Gardner (1971), Burroughs and others (1972), Clayton and Arnold (1972), Megahan (1972), Clayton (1983), Megahan (1983), and Vincent (1985).

BMP 104—Rule 4.b.v. Design culvert installations to prevent erosion of the fill.

Bachmann 1958, Silver and Crystal Creeks, near Pierce—This study used a paired-watershed approach (p. 9) to investigate the effects of logging and logging road construction on selected physical, chemical, and biological features of northern Idaho trout streams (pp. 2-3). Measured predisturbance (1955 and 1956) turbidities ranged from 0.25 to 2.10 parts per million in Silver Creek, and from 0.6 to 6.9 parts per million in Crystal Creek (p. 34).

In the Crystal Creek drainage, which had road construction activity in 1956 and 1957, a vegetated buffer strip (width unspecified) was left between the road and stream, except at stream crossings. Roadfills at stream crossings were not treated (pp. 21-22). Temporarily increased turbidity (90 parts per million) and a sediment deposit were associated with culvert installation (pp. 22, 35, 37). Increases in turbidity were noted only during rain, snowmelt, and direct channel disturbances; sediment sources were predominantly at stream crossings (pp. 35, 37). Although turbidity sampling was not adequate to define average or maximum values (p. 37), turbidity was different above and below road crossings, and also between the roaded and unroaded watersheds (p. 35).

Haupt and Others 1963, Zena Creek Logging Study Area, Payette National Forest—Following three long-duration, low-intensity storms of unprecedented total rainfall (pp. 4-5), erosion was visually compared on insloped and outsloped road sections of a newly constructed logging road. Both insloped and outsloped sections had earthen cross drains spaced 30 to 90 feet apart (p. 2). Shoulders and fills had been seeded and mulched with chopped hay and asphalt binder (p. 3).

Insloped sections had less erosion damage than outsloped sections. The worst damage on outsloped sections occurred at the mouths of swales on incurves (p. 6). The authors recommended that culverts placed in major ravines be laid on the original grade so they drain into the original channel rather than on the fill of the incurve (p. 8).

Gonsior and Gardner 1971—When investigating slope failures in the Idaho Batholith, the authors measured low soil permeablilities. Permeability can be expected to decrease over time in roadfills and elsewhere; this must be considered in the design of culverts (p. 12). The authors stressed the need to evaluate surface and subsurface flow conditions when locating and designing roads (p. 33).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—During the construction period and the early period of use, an engineering research team evaluated a road designed to minimize watershed impacts. The authors recommended that dimpled connecting bands not be used on culverts because sections sometimes leak or separate. They also recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10). Proper bedding of culverts and compaction of backfill material are discussed (p. 12).

Burroughs and King 1989, Horse Creek Study Area and Rainy Day Road, Nez Perce National Forest—Rill volumes and sediment flow transport distances were measured for 2 years after road construction in the Horse Creek Study Area. One of the longest average transport distances (72.8 feet) for sediment flows below road fillslopes resulted when rills formed below relief culvert outflows or when sediment flows from rills combined with the paths of flows from relief culverts (pp. 8-9). Transport distances below relief culverts were not strongly correlated with the length of road contributing water to the culvert, the road gradient, or the sideslope gradient (p. 10). A figure (p. 10) shows the cumulative frequency of sediment travel distances for flows influenced by relief culverts; this might apply to similar sites with gneiss and schist parent material and sideslope gradients of 30 to 40 percent (p. 11).

BMP 105—Rule 4.b.v. Plan drainage structures to achieve minimum direct discharge of sediment into streams.

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—During the construction period and the early period of use, an engineering research team evaluated a road designed to minimize watershed impacts. The authors stressed the need for careful planning to control sediment from the cutslope and ditch. They recommended routing water down the road surface rather than along the toe of the cutslope. They also recommended providing for sediment filtering or settling before runoff leaves the road surface, or discharging drainage far enough from streams to provide for infiltration and clarification (p. 21).

BMP 106—Rule 4.b.vi. Plan stream crossings to be minimum in number.

Bachmann 1958, Silver and Crystal Creeks, near Pierce—This study used a paired-watershed approach (p. 9) to investigate the effects of logging and logging road construction on selected physical, chemical, and biological features of northern Idaho trout streams (pp. 2-3). Measured predisturbance (1955 and 1956) turbidities ranged from 0.25 to 2.10 parts per million in Silver Creek, and from 0.6 to 6.9 parts per million in Crystal Creek (p. 34).

In the Crystal Creek drainage, which had road construction activity in 1956 and 1957, a vegetated buffer strip (width unspecified) was left between the road and stream, except at stream crossings. Roadfills were not treated at stream crossings (pp. 21-22). Temporarily increased turbidity (90 parts per million) and a sediment deposit were associated with culvert installation (pp. 22, 35, 37). Increases in sedimentation and turbidity were noted at crossings of some small tributaries (p. 25). However, most of the material that eroded from the road prism was not delivered to the stream due to the distance between the road and the stream (p. 25). Increases in turbidity were noted only during rain, snowmelt, and direct channel disturbances; sediment sources were predominantly at stream crossings (pp. 35, 37). Although turbidity sampling was inadequate to define average or maximum values (p. 37), turbidity was different above and below road crossings, and also between the roaded and unroaded watersheds (p. 35).

King and Gonsior 1980, Horse Creek Study Area, Nez Perce National Forest—Limited sediment sampling at monitoring stations above culvert inlets ("A stations"), below culvert outlets ("B stations"), and 100 yards downstream ("C stations") provided indications of the first-year effects (1978-1979) of road construction at stream crossings (p. 3, 7).

At one crossing, pioneering operations provided an estimated 12.3 pounds of excess sediment at the C station (p. 9) compared to 0.2 pounds for permanent culvert installation. The low value for permanent culvert installation was attributed to "dewatering," or routing the streamflow around the construction site during installation. At another crossing, which was not dewatered, 46 pounds of sediment passed the C station during permanent culvert installation (p. 9).

Shortly after construction, sediment concentrations at the crossings returned to preconstruction levels except during rainstorms, during which the sediment loads increased by about 100 to 1,000 times over the normal load at the B stations (p. 11). During the first snowmelt period following construction, the road contributed 400 pounds of sediment at one stream crossing, based on measurements at the monitoring stations (p. 11). The following summer (1 year after construction), sediment loads during storms were up to 10 times greater than normal (p. 15).

See King (1981) for a more complete report.

King 1981, Horse Creek Study Area, Nez Perce National Forest—Sediment sampling at monitoring stations above culvert inlets ("A stations"), below culvert outlets ("B stations"), and 100 yards downstream ("C stations") was used to evaluate the effects of road construction activities at stream crossings. Summaries are given of some of these measurements for road pioneering activities in 1978 and 1979 (p. 62). Sediment due to pioneering and temporary culvert placement varied from 0.00 to 212.59 pounds, averaging 40.65 pounds, when measured at C stations. These values do not necessarily represent total sediment produced; in some cases flows may have been inadequate to provide transport to the C stations (pp. 61, 63). Delivery ratios from the B to C stations varied from 14.4 to 72.5 percent for three stream crossings tested (p. 64). The mean peak sediment concentration measured at 10 C stations during pioneering activities was 2,256 milligrams per liter (p. 63). Clearing of right-of-way slash at one crossing contributed 1.56 pounds of sediment at the C station; the peak concentration was 88.1 milligrams per liter (p. 63). Sediment concentrations upstream from the activities were generally less than 5 milligrams per liter (p. 63).

Sediment measurements during permanent culvert installation in 1978 and 1979 are also summarized (p. 67). For eight culvert installations, the sediment measured at the C stations varied from 0.22 to 603.75 pounds, averaging 82.96 pounds (p. 66). Concurrent measurements were available at the B stations in some cases. It appears that C station values were strongly influenced by the lack of sediment transport in some cases, and by channel scour in others (p. 66). Peak sediment concentrations measured at the C stations during 10 permanent culvert installations varied from 5.3 to 39,243 milligrams per liter, averaging 5,924.8 milligrams per liter (p. 70).

See Rule 4.b.i., minimum road construction in streamside protection zones and road buffer strip rules (BMP's 86 through 88).

BMP 107—Rule 4.b.vi. Plan all culvert installation on Class I streams to provide for fish passage.

No references were found.

BMP 108—Rule 4.b.vii. Consider reuse of existing roads when reuse or reconstruction would result in the least long-run impact on site productivity, water quality, and fish and wildlife habitat.

Megahan 1974b, four sites in the Idaho Batholith: Deep Creek, Silver Creek, Bogus Basin, Deadwood River—Data on roadfill erosion or total road prism erosion were used to develop a negative exponential equation showing surface erosion on severely disturbed granitic soils over time. By far the greatest percentage of erosion occurs in the first and second years after construction (p. 12). In the first year, erosion rates are three orders of magnitude (about 1,000 times) greater than on undisturbed lands, where rates average 0.07 tons per square mile per day (p. 12). Additional disturbances result in new cycles of surface erosion (p. 13).

No references were found specific to reuse compared to new road construction; however, numerous references show decreases over time (ranging from the first season to the first 3 years) in total road erosion or erosion on various components of the road prism. Megahan (1974b) has the largest data set and the longest records. Because he dealt most directly with the concept of erosion time trends, his research was summarized here.

Rule 4.c. Road Construction

Forty BMP's (109 through 148) were evaluated. These addressed several topics associated with road construction:

- Placement of excess material from road construction (BMP's 109 through 113, 115, and 116);
- Surface stabilization of material exposed during the construction process (BMP's 117 through 122);
- Fillslope stability (BMP's 123 through 127);
- Windrows (BMP's 128 and 129);
- Road construction in or near streams (BMP's 130 through 132);
- Maintenance of outsloped roads (BMP's 133 and 134);
- Quarry drainage (BMP 135);
- Prevention of fill erosion due to drainage structures (BMP's 136 through 142);
- Drainage on uncompleted roads (BMP's 143 and 144);
- Minimum grade of relief culverts (BMP 145);
- Earthwork during wet periods (BMP 146);
- Hazards from overhanging banks and trees (BMP's 147 and 148).

Placement of Excess Material

No references were found on the placement of road construction debris, overburden, and other materials. The reader is referred to the General Erosion Research Summary for information on the "stable location" requirement of these BMP's. One study addressed clearing drainage ways of debris generated during construction. King (1981, p. 63) observed short-term increases in sediment during clearing of right-of-way slash at a stream crossing; he concluded that normal slash clearing operations would have minimal effects on stream sedimentation.

Stabilization of Exposed Material

Several studies evaluated various means of stabilizing cut and fillslopes. Most of the research has been done on fillslopes, and most looked at combinations of treatments listed in the BMP's rather than individual treatments (for example, seeding, mulching and netting compared to a control, instead of comparing seeding to a control, mulching to a control, and netting to a control).

An early fillslope study in the Idaho Batholith (Ohlander 1964, p. 19) compared a seed and fertilizer control treatment to the use of seed and fertilizer coupled with five other treatments. These were surface holes, chipped slash, straw and asphalt binder, and one or three layers of paper netting. The one layer of paper netting and the asphalt binder and straw treatments were the most effective in terms of both sediment reduction and vegetation production (p. 29). Another fillslope study in the Idaho Batholith (Bethlahmy and Kidd 1966, p. 4) compared an unseeded control with various treatments. In general, combinations of seed, fertilizer, mulch, and netting were the most effective.

Megahan (1974a, p. 14) found that mulch and netting used in conjunction with seeding or planting significantly reduced fillslope surface erosion in the Idaho Batholith. Planted trees (without mulch) also reduced surface erosion (pp. 13-14) and had better survival rates than seeded trees or seeded grass (p. 8). Trees were also expected to reduce mass erosion hazards (p. 3). Fertilizer increased tree growth (p. 11). He recommended that planted trees, fertilizer, mulch, and netting be used to attain maximum erosion control (p. 15).

In the Silver Creek Study Area, 16 fillslope treatments were tested (Megahan and others 1992, p. 59). As a group, treatments combining revegetation and surface amendments were more effective in controlling erosion than either revegetation or surface amendments alone (p. 63). The most effective individual treatment combined straw, crimping, seed, fertilizer, and transplants (p. 59). A companion study on cutslopes in the study area (Boise State University, Department of Geology and Geophysics 1984, p. 20) found that dry seeding, hydroseeding, and hydroseeding plus terracing all significantly reduced cutslope erosion.

Several references reported on studies of cutslope and fillslope erosion control in northern Idaho. King (1984, p. 2) summarized results from the Horse Creek Study Area. Three treatments (plus a control) on cut and fillslopes were evaluated for 3 years after road construction. The treatments included: straw mulch with asphalt tackifier, seed, and fertilizer; cellulose fiber hydromulch, seed, and fertilizer; dry seeding; and no treatment. On cutslopes, straw mulch reduced erosion by 32 to 47 percent, the only treatment that significantly reduced erosion. All of the treatments were comparable in reducing fillslope erosion. Relative to the control, the treatments reduced erosion 24 to 30 percent for fills from 20 to 40 feet high, and from 46 to 58 percent for fills less than 20 feet high.

Also in the Horse Creek Study Area, Burroughs and King (1985, p. 186) applied simulated rainfall to fillslopes to evaluate the relative erosion control of an established dense stand of grass and wood excelsior mulch with nylon netting over loose soil, compared with loose soil. The grass treatment reduced sediment by 99.5 percent and the mulch treatment reduced erosion by 91 percent compared with the bare, loose soil (p. 189). They concluded that mulch could provide immediate protection, while a dense stand of grass provided effective long-term protection (p. 189).

The importance of fill compaction in the Idaho Batholith was addressed in several reports. Lack of fill compaction was identified by Gonsior and Gardner (1971, p. 31) as an important factor contributing to failures, through liquefaction under saturated conditions, and through reduced resistance to shear under all conditions. Similarly, Hartsog and Gonsior (1973, pp. 6-7) noted that lack of fill compaction was partially responsible for sloughing, settlement cracks, and liquefaction during heavy rainstorms. Clayton and Arnold (1972) recommended compaction of fillslopes constructed in weathering class 7 rock (the most highly weathered) to reduce the chance of mass failure (p. 16).

Also in the Idaho Batholith, Megahan and others (1992, pp. 57-58) evaluated fillslope erosion control of six construction techniques. Three methods of embankment placement were tested: side cast, layer placed, and controlled compaction. The three methods did not differ significantly with respect to surface erosion; however, controlled compaction was recommended to reduce mass erosion on high hazard sites (pp. 61-62). Surface rolling with a grid roller, intended to compact the surface of the fill, significantly increased surface erosion rates for all of the embankment placement methods. On average, erosion increased from 9.2 (no rolling) to 28.9 (with rolling) metric tons per hectare per year (p. 61).

Burroughs and King (1989, p. 2) noted that factors influencing the effectiveness of fillslope treatments include: timing, type, and rate of application of treatments, as well as insloping or outsloping of the road surface, soil erodibility, and slope gradient. Many of the same variables influence cutslope erosion control, although erosion processes may be different on steep cutslopes (p. 11). Aspect, elevation, soil type, and frost heaving may be important (p. 12). Ditch maintenance may reinitiate cutslope erosion processes by undercutting the slope (pp. 12-13).

No references were found regarding riprap for stabilization of exposed material.

Fillslope Stability

No references were found regarding the incorporation of snow, ice, and frozen soil into roadfills. Based on their analyses of slope failures in the Idaho Batholith, Gonsior and Gardner (1971, pp. 31-33) stressed that logs, stumps, large roots, and debris should always be removed from fill material. For research on the effects of compaction on fill stability, see BMP 118, stabilization of exposed material by compacting, and the General Erosion Research Summary.

Windrows

Only a few studies actually measured the effectiveness of windrows. One in the Horse Creek Study Area was reported most completely by Cook and King (1983). Windrow construction at five stream crossings totaled 1,190 feet in length (pp. 2-4). Comparisons (between windrowed and nonwindrowed fill sections) of sediment in collection troughs below the fills indicated that 99 percent of eroded fill material was retained within the windrows (p. 3). Average sediment volumes in troughs below windrows was 0.325 cubic feet per 100 feet of road for fill lengths of 0 to 10 feet and 0.650 cubic feet per 100 feet of road for fill lengths of 10 to 20 feet. Corresponding values for nonwindrowed fills were 35.85 cubic feet per 100 feet of road for fill lengths of 0 to 10 feet and 64.30 cubic feet per 100 feet of road for fill lengths of 10 to 20 feet (pp. 3-4). Surveys of rills and gullies in the fills provided another means of estimating windrow performance. Based on these data it was estimated that windrows retained 75 to 85 percent of the eroded material (p. 4).

Only seven sediment flows were observed below the windrowed fills in the 3-year study period; three of these had sediment delivery to the stream. When windrows were breached, it was usually because of slumping associated with snowmelt saturation of the fill (p. 4). Average transport distance for sediment flows was 3.8 feet below windrows. For nonwindrowed fills, the average transport distance was 41.4 feet for flows originating in slumps, and 24.2 feet for flows originating in unslumped areas of the fill (p. 4).

Another study in the Horse Creek Study Area (Burroughs and King 1985, pp. 186-187) compared fillslope sediment generated by simulated rainfall for a loose soil control and a loose soil with filter windrow treatment. The windrow treatment reduced sediment by 87 percent compared with the control (p. 189). This study indicated that windrows could provide effective protection immediately following construction; other observations in the study area confirmed that windrows were still effective 7 years after construction (p. 190).

Research in the Silver Creek Study Area (Ketcheson and Megahan 1990) showed no significant differences in sediment flow volume or length between fills with and without cull logs placed at the toe (p. 3). However, field observations elsewhere in the Idaho Batholith have confirmed the effectiveness of windrows (Hartsog and Gonsior 1973, p. 5).

Several other reports present data that have implications for windrows. As indicated in the sections on buffer strips, several studies (Haupt 1959a,b; Packer and Christensen 1964; Packer 1967; Burroughs and King 1989; Ketcheson and Megahan 1990; Burton n.d.) have shown the importance of slope obstructions in limiting sediment movement. See summaries of these references under the buffer strip rules (BMP's 86 through 88) or the windrow rules (BMP's 128 and 129).

Road Construction In or Near Streams

See Rule 4.b.i., minimum road construction in stream protection zones and road buffer strip rules (BMP's 86 through 88) and Rule 4.b.vi., minimum stream crossings (BMP 106).

Maintenance of Outsloped Roads

Two reports noted the difficulties in maintaining outsloped roads. Hartsog and Gonsior (1973, p. 13) observed ruts from logging activities that redirected the flow of water on an outsloped road. They felt that concentrations of water would occur on almost any outsloped road under normal traffic conditions (p. 20). They also observed that a berm left by a grading operation concentrated water that eventually drained onto the fillslope, and was a major source of erosion during a heavy rainstorm (p. 13).

Burroughs and King (1989, p. 16) observed a similar situation where an unintentionally constructed berm concentrated flow that resulted in high fillslope erosion rates. They recommended insloping to the ditch or providing uniform distribution of outslope drainage. Road maintenance employees would need to be careful to avoid creating berms and to maintain uniform drainage on outsloped portions of the road.

See BMP's 97 and 98 for more information on insloping and outsloping.

Quarry Drainage

Only one study was found that addressed quarries. Bachmann (1958) measured turbidities near a quarry site as part of a study of the effects of logging and road construction on various stream characteristics. Rock was quarried in the Crystal Creek watershed during road construction activities (p. 22). The quarry was adjacent to a small tributary, and was a major source of sediment (p. 30). Sediment deposits nearly covered the channel below the quarry. Turbidities measured at the sampling station near the quarry were among the highest in the study (p. 30). For example, values of 350 parts per million of sediment were measured during snowmelt; after a 12-hour rain, 2,169 parts per million of sediment were measured (p. 36). Pre-disturbance turbidities ranged from 0.6 to 6.9 parts per million in Crystal Creek (p. 34).

Preventing Fill Erosion Due to Drainage Structures

Most of the reports summarized under these BMP's presented qualitative observations or recommendations rather than quantitative data. For example, Haupt and others (1963) observed storm damages associated with cross drains on insloped and outsloped road sections. All earthen cross drain outlets were deeply eroded on the outsloped portions (p. 6). Cross drains also generated fill erosion on insloped sections. Cross drain outlets were the only site where surface drainage overtopped the inslope (p. 7). Based on their observations, the authors recommended that if earthen cross drains are to be used, they should drain on the outcurve (p. 8).

During the construction period and the early period of use, Hartsog and Gonsior (1973) evaluated a road designed to minimize watershed impacts. The authors recommended that dimpled connecting bands not be used on culverts, to prevent sections from separating or leaking. They also recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10). Proper bedding of culverts and compaction of backfill material were discussed (p. 12). Gonsior and Gardner (1971) stressed the need to evaluate surface and subsurface flow conditions when locating and designing roads (p. 33).

Research in the Horse Creek Study Area evaluated the influence of relief culverts on sediment flow transport distances for 2 years after road construction (Burroughs and King 1989). One of the longest average transport distances (72.8 feet) for sediment flows below road fillslopes resulted when rills formed below relief culvert outflows or when sediment flows from rills combined with relief culvert flows (pp. 8-9). Transport distances below relief culverts were not strongly correlated with the length of road contributing to the culvert, the road gradient, or the sideslope gradient (p. 10). A cumulative frequency distribution of sediment travel distances for flows influenced by relief culverts was developed (p. 10).

No references were found regarding the use of riprap or vegetative matter to minimize erosion of the fill associated with drainage structures. For related references, see Rule 4.c.iii., stabilization of exposed material by seeding (BMP 117), mulching (BMP 121), and other suitable means (BMP 122), and the General Erosion Research Summary. Also, no references were found that directly addressed time trends in fill erosion due to outflow from drainage structures. However, numerous studies show time trends in erosion that illustrate the need for timely application of erosion control measures; some of these are listed under BMP 138.

Drainage on Uncompleted Roads

No references were found that dealt directly with erosion due to lack of drainage structures on uncompleted roads during spring and fall runoff. However, many references have implications for this rule. Several cross-references are listed under BMP's 143 and 144.

In the South Fork Salmon River drainage, Hartsog and Gonsior (1973) evaluated the construction and initial performance stages of a road designed to minimize environmental impacts. The road was designed as an outsloped road, but did not function as such because skidded logs and skidding tractors rutted the road surface (p. 13). During a heavy 4-day rainstorm on Labor Day weekend, this road had considerable erosion, that was largely attributed to incomplete shaping and grading (p. 19). A half-mile length of pioneer road had no erosion, even though it had no drainage structures installed. This was attributed to minimal disturbance of natural drainage patterns, flat grade or short stretches of unbroken grade, and loose, absorbent soil conditions (p. 15). Based on these observations, the authors suggested constructing a minimum standard contour road with a rolling grade and installing drainage structures during logging operations. Each road section could be completed to the desired standard when log hauling was finished on that section (p. 19).

Based on observations in the Silver Creek Study Area, Megahan and others (1986) noted that construction phase erosion often depended more on the stage of road construction during rainstorms than on the final design features of the road. They recommended that temporary berms be constructed to protect fills when storm threats are high (p. 39).

Minimum Grade of Relief Culverts

No references were found relating to this BMP.

Earthwork During Wet Periods

Two studies with simulated rainfall showed that sediment yields from rutted road sections were greater than those from unrutted sections. In northern Idaho, Burroughs and others (1983b, p. 16) measured a 108 percent increase in sediment associated with ruts. They noted that surface armoring might not occur if traffic is present (p. 22). In eastern Idaho, Foltz and Burroughs (1990, pp. 273-274) found that a rutted road could produce from 1.0 to 2.1 times as much sediment as an unrutted road, depending on the moisture conditions. They recommended road closures to prevent rutting during wet weather (p. 275).

In the Silver Creek Study Area, Megahan and others (1991) tested several site factors as predictors of fillslope erosion during snow-free periods. Only ground cover density and rainfall erosivity (an index based on rainfall intensity) were statistically significant (p. 56).

Hazards from Overhanging Banks and Trees

No references were found on the hazards of overhanging banks. Several references stressed the contributions of trees to slope stability, and many recommended leaving trees above and below roads whenever the hazards are not too great.

For example, Gonsior and Gardner (1971, pp. 31-32) felt live trees were important sources of slope stability by mechanically reinforcing the soil and depleting soil moisture (and possibly slowing subsurface weathering by moderating temperatures). Burroughs and Thomas (1977, p. 16) evaluated the tensile strength of Douglas-fir roots, and found them to be an important factor increasing slope stability. Root tensile strength decreases rapidly in the first year after tree felling, and continues to decrease gradually over time. Megahan and others (1979, p. 133) found that landslides were most common 4 to 10 years after logging; landslide frequencies remained elevated for 20 years after logging. These time trends were attributed to the increasing loss of root strength through decay, interacting with growth of new roots over time to again stabilize the slope (p. 132). The slope stability analyses of Gray and Megahan (1981, p. 20) showed that many sites in the Idaho Batholith are in a state of marginal equilibrium, and may fail when roads are constructed or trees are harvested. They recommended leaving buffer zones of trees above and below haul roads, although they noted that the stability benefits must be weighed against the safety hazards (p. 21).

Two references documented the role of tree roots in slowing erosion originating on cutslopes in the Silver Creek Study Area. Megahan and others (1983, p. 27) evaluated long-term (45-year) cutslope erosion rates. Reductions in soil erosion due to tree roots were observed in the field and were also apparent from the data. Megahan and Bohn (1989, p. 509) monitored a progressive mass failure originating on a cutslope; they noted that mass erosion hazards of this type are increased if timber is harvested above the roadcut. Also, tree roots were observed to slow uphill progress of failure and to retain soil that would otherwise collapse (pp. 504, 506).

Research Results by Best Management Practice

BMP 109—Rule 4.c. Place debris associated with road construction in such a manner as to prevent entry into streams.

No references were found.

BMP 110—Rule 4.c. Place overburden associated with road construction in such a manner as to prevent entry into streams.

No references were found.

BMP 111—Rule 4.c. Place other materials associated with road construction in such a manner as to prevent entry into streams.

No references were found.

BMP 112—Rule 4.c. Deposit excess material on stable locations outside the stream protection zones.

No references were found; see the General Erosion Research Summary for references regarding stable locations.

BMP 113—Rule 4.c. Deposit slash on stable locations outside the stream protection zones.

No references were found. See the General Erosion Research Summary for references regarding stable locations.

BMP 114—Rule 4.c.i. Construct roads in compliance with the planning guidelines of Rule 4.b.

See summaries under individual BMP's in Rule 4.b.

BMP 115—Rule 4.c.ii. Clear drainage ways of all debris generated during construction that potentially interferes with drainage or water quality.

King 1981, Horse Creek Study Area, Nez Perce National Forest—Sediment sampling at monitoring stations above culvert inlets ("A stations"), below culvert outlets ("B stations"), and 100 yards downstream ("C stations") was used to evaluate the effects of road construction activities at stream crossings. Clearing right-of-way slash at one crossing contributed 1.56 pounds of sediment at the C station; the peak concentration of sediment during the operation was 88.1 milligrams per liter (p. 63). Sediment concentrations upstream from pioneering activities were generally less than 5 milligrams per liter (p. 63). Based on these measurements and visual observations at other crossings, the author concluded that normal slash clearing operations have minimal effects on stream sedimentation (p. 63).

See Rule 3.f.i., removal of slash during harvesting operations (BMP 51).

BMP 116—Rule 4.c.ii. Clear drainage ways of all debris generated during maintenance that potentially interferes with drainage or water quality.

No references were found.

BMP 117—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: seeding (first alternative).

Ohlander 1964, Zena Creek Study Area, Payette National Forest—Sediment and vegetation were measured on fillslope erosion plots on south aspect slopes in the year following road construction. All plots except the control were seeded and fertilized; six treatments were tested: chipped slash, one layer paper netting, three layers paper netting, asphalt binder and straw, surface holes, and control (p. 19). The treatment using one layer of paper netting had the highest vegetation production, with asphalt binder and straw second (p. 31). (These two treatments also had the lowest sediment production; see the mulch rule, BMP 121, and the other suitable means rule, BMP 122.) Average vegetation production measured in the fall was 20 pounds per acre for the control, 2,039 pounds per acre for the one layer paper netting treatment, and 1,599 pounds per acre for the asphalt binder and straw treatment. All treatments significantly increased vegetation production as compared to the control; the lowest value of production was 900 pounds per acre for the chipped slash plots (p. 29).

Bethlahmy and Kidd 1966, Bogus Basin Road, Boise National Forest—Eight fillslope treatments were tested in plot studies, including various combinations of contour furrows, seed, fertilizer, holes, straw mulch, polymer emulsion, paper netting, jute netting, chicken wire netting, and straw mulch with asphalt emulsion (p. 2). All plots except the control were seeded and fertilized. The plots were on the fillslope of a newly constructed road. The fillslope had a gradient of 80 percent and a southeast aspect. Six measurements were made over 11 months.

Treatments were placed in three general groups: seed and fertilizer (Group A); seed, fertilizer, and mulch (Group B); seed, fertilizer, mulch, and netting (Group C). In Group A, one plot had contour furrows, seed, fertilizer, and holes; the other plot had polymer emulsion, seed, and fertilizer (p. 2). Both treatments had greater cumulative erosion than the control, with an average increase of 15 percent. Groups B and C both reduced erosion compared to the control (p. 4). See the mulch rule, BMP 121, and the other suitable means rule, BMP 122.

Jensen and Finn 1966, Zena Creek Study Area, Payette National Forest—Watershed conditions were evaluated throughout the Zena Creek Study Area. The authors noted that most previous road stabilization attempts on decomposed granitic soils, including grass seeding, were unsuccessful. Cutslope surfaces remained raw and unvegetated, and grass roots were inadequate to stabilize steep sandy fillslopes when moisture content was high. Complete stabilization of cuts and fills on decomposed granitic soils appeared infeasible for slopes exceeding 45 percent (p. 76).

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—Based on extensive field and laboratory analyses of slope failures, the authors recommended revegetating fill surfaces as soon as possible after construction (p. 33).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance stages of a road designed to minimize environmental impacts. The authors stressed the need to accelerate revegetation of cuts and fills (p. 22).

Megahan 1974a, Deadwood River Road, Boise National Forest—Fillslope plot studies evaluated surface erosion control, growth, and survival associated with ponderosa pine, grass, and surface amendments. The potential of ponderosa pine to reduce mass erosion was discussed and assumed, although it was not tested in this study (pp. 2-3, 15). The roadfill was 11 years old when the plots were installed, and had been unsuccessfully seeded to grass at least twice before the study (p. 4). The fillslope had a southwest aspect, and a gradient of 70 to 75 percent (p. 4). Nine treatments plus a control (pp. 5-6) were evaluated for longer than 3 years (p. 7).

Survival data were reported for planted trees, seeded trees, and seeded grass by years (p. 8). Survival was poor for seeded grass and seeded trees, but excellent for planted trees. After 4 years, 5 percent of seeded trees survived, compared to 97 percent of planted trees. Seeded grass decreased from 17.2 to 0.8 plants per square foot over the 4-year period. Grass vigor may have decreased due to a severe grasshopper infestation (p. 8).

Erosion did not differ significantly among the various treatments that used mulch (p. 13), which included the seeded grass and the seeded trees, as well as some of the planted trees (p. 5). The erosion control was attributed to the mulch and erosion net rather than to the seeding (pp. 13-15). See the mulch rule, BMP 121, and the other suitable means rule, BMP 122.

King 1979, Horse Creek Study Area, Nez Perce National Forest—Fillslope erosion on hydroseeded slopes was measured for 1 year after construction. Rill and gully erosion processes were dominant in the summer; slumping was important during spring snowmelt (p. 11). Erosion volumes estimated by measuring rills and gullies were 9.9 cubic feet per 100 feet of road (p. 11). Of the total, 7 cubic feet eroded per 100 feet of road length during summer thunderstorms the year of construction; 2.9 cubic feet eroded per 100 feet of road during spring snowmelt the following year (p. 4). Slump surveys conducted on selected road sections showed the volume of displaced material averaging 4.36 cubic feet per 100 feet of road; however, not all of this material left the fill (p. 10).

On two other roads, fillslopes were seeded and mulched (straw mulch with asphalt tackifier). These roads had average erosion volumes of 6.1 and 5.1 cubic feet per 100 feet of road as measured in the rill and gully survey. Slump volumes were 21.91 and 13.57 cubic feet per 100 feet of road (p. 10).

See other Horse Creek publications listed under this rule for followup reports.

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—The authors compared road segments that were similar except for slope treatments. Hydroseeded fills with no mulch showed 45 percent less fillslope erosion (33.1 cubic feet per 100 feet of road) than untreated controls (59.71 cubic feet per 100 feet of road) during the first summer. However, differences were not statistically significant (p. 15). Fillslope gradients were 1.5:1 (p. 7).

Class 1 cutslopes (0-10 feet high) that were hydroseeded and mulched (straw mulch with an asphalt tackifier) showed significantly less erosion (73 percent reduction) than untreated cutslopes for the first year after construction. Cumulative erosion was 15 cubic feet per 100 feet of road for untreated cutslopes, compared to just 4 cubic feet per 100 feet of road for treated cutslopes (p. 21).

Carlton and others 1982, Gospel Hump management areas, Nez Perce National Forest—Fillslope erosion on roads constructed in 1978 and 1979 was evaluated by two methods from the spring of 1980 through the fall of 1981. The rill survey method was considered more representative of actual erosion rates than the bordered trap method (pp. 31, 38). All fillslopes were fertilized, seeded, and hydromulched (p. 13). Cumulative erosion volumes were about 65 cubic feet per 100 feet of road in the spring of 1980 and 85 cubic feet per 100 feet of road in the fall of 1981 (p. 30). No data were collected on untreated cutslopes, so erosion reduction due to treatment cannot be assessed.

Cook and King 1983, Horse Creek Study Area, Nez Perce National Forest—Erosion was evaluated for a 3-year period after construction on 1.5:1 road fillslopes that had been seeded, hydromulched, and fertilized. Average erosion volume measured in collection troughs below the fills was 35.85 cubic feet per 100 feet of road for Class 1 (0-10 feet long) fillslopes and 64.30 cubic feet per 100 feet of road for Class 2 (10-20 feet long) fillslopes (p. 3). No measurements were made on untreated fillslopes, so erosion reduction due to treatment cannot be evaluated.

Boise State University, Department of Geology and Geophysics 1984, Silver Creek Study Area, Boise National Forest—Collection troughs were used to evaluate erosion from cutslopes with gradients ranging from 0.95:1 to 1.8:1 for 3 years after road construction. All of the treated cutslopes (dry seed, hydroseed, hydroseed plus terrace) had much lower erosion than untreated cutslopes. Untreated cutslopes yielded an average of 15 times as much sediment as the dry seeded slopes. Sample sizes for the other treatments (hydroseed and hydroseed plus terrace) were much smaller and comparisons may be misleading (p. 20).

For results of fillslope studies, see Megahan and others (1991) and Megahan and others (1992).

King 1984, Horse Creek Study Area, Nez Perce National Forest—Three treatments (plus a control) on cut and fillslopes were evaluated for 3 years after road construction. The treatments included: straw mulch with asphalt tackifier, seed, and fertilizer; cellulose fiber hydromulch, seed, and fertilizer; dry seeding; and no treatment.

On cutslopes, only the straw mulch treatment significantly reduced erosion, by 32 to 47 percent (p. 2). All of the treatments were comparable in reducing fillslope erosion. Relative to the control, the treatments reduced erosion by 24 to 30 percent for fills 20 to 40 feet high, and by 46 to 58 percent for fills less than 20 feet high (p. 2).

See other Horse Creek reports in this rule for additional information.

Burroughs and King 1985, Horse Creek Study Area, Nez Perce National Forest—Simulated rainfall was applied to 1.5:1 (67 percent) fillslopes to evaluate the relative erosion control effectiveness of an established dense stand of grass and wood excelsior mulch with nylon netting over loose soil, compared to loose soil. The grass stand had 97 percent cover of grass, litter, and stones greater than 0.25 inches in diameter; species were primarily orchardgrass and smooth brome. Four applications of simulated rainfall were made for each treatment (pp. 186-187). The grass treatment reduced sediment by 99.5 percent, and the mulch treatment reduced sediment by 91 percent, compared to the bare, loose soil (p. 189). Mulch can be used to provide immediate protection, while a dense stand of grass provides effective, long-term protection (p. 189).

Burroughs and King 1989, literature review, various sites—The authors reviewed road erosion studies from Idaho and elsewhere. Only new Idaho data (not summarized elsewhere in this report), general observations, and recommendations will be included in this summary.

Erosion control treatments on one part of the road prism may influence sediment yield from other parts of the road prism (p. 1). Sediment contributions from the road prism components may vary over time. At one stream crossing in the Horse Creek Study Area, 80 percent of the sediment measured the first year after construction entered from the fillslope side of the road; by the fourth year, 83 percent was entering by the ditch system. The road tread was unsurfaced and crowned; cuts and fills were not treated (pp. 15-16).

Factors influencing the effectiveness of fillslope treatments include: timing, type, and rate of application of treatments, as well as insloping or outsloping of the road surface, soil erodibility, and slope gradient (p. 2). Many of the same variables influence cutslope erosion control, although erosion processes may be different on steep cutslopes (p. 11). Aspect, elevation, soil type, and frost heaving may be of importance (p. 12). Ditch maintenance may initiate cutslope erosion processes by undercutting the slope (pp. 12-13).

Based on observations on the Nez Perce National Forest, dry seeding is not recommended for 0.75:1 cutslopes unless cutslope height is less than 6 to 8 feet. Sediment reductions for dry seeding are estimated at 10 percent for 0.75:1 cutslopes more than 8 feet high, and 36 percent for 1:1 cutslopes, for the first year following construction (p. 11).

After grass is established on cutslopes, it can reduce sediment an estimated 86 to 100 percent, depending on density of coverage (p. 12).

Megahan and others 1992, Silver Creek Study Area, Boise National Forest—Erosion plots were used to evaluate the effectiveness of six construction techniques and 16 postconstruction treatments in controlling fillslope erosion for 3 years after road construction. Fills had design slopes of 1.5:1 or 1.33:1.

The steep slope seeder treatment (seed and fertilizer) decreased erosion by 52 percent (or 4.9 tons per acre per year) relative to the control. Other treatments combined seeding with transplants, mulches, and other techniques (see the mulch rule, BMP 121, and other suitable means rule, BMP 122).

See the General Erosion Research Summary for additional information.

BMP 118—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: compacting (second alternative).

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—The authors conducted extensive field and laboratory analyses of slope failures. Lack of fill compaction appeared to be an important factor contributing to failures, through liquefaction under saturated conditions, and through reduced resistance to shear under all conditions (p. 31). The authors recommended compaction of all fillslopes, with the degree of compaction depending on design standards and the properties of the fill material (p. 33).

Clayton and Arnold 1972, Idaho Batholith—Based on their studies of the properties of granitic rock, the authors recommend compacting fillslopes constructed in weathering class 7 rock, the most highly weathered classification. Landslides are common when roads are cut through class 7 rock (p. 16).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance stages of a road designed to minimize environmental impacts. Lack of fill compaction was partially responsible for sloughing, settlement cracks, and also for liquefaction during a heavy rainstorm (pp. 6-7).

Megahan and others 1992, Silver Creek Study Area, Boise National Forest—Erosion plots were used to evaluate the effectiveness of six construction techniques and 16 postconstruction treatments in controlling fillslope erosion for 3 years after road construction. Fills had design slopes of 1.5:1 or 1.33:1.

Three methods of embankment placement were tested: side cast, layer placed, and controlled compaction. There was no significant difference among the three methods with respect to surface erosion; however, controlled compaction was recommended to reduce mass erosion on high hazard sites. Surface rolling with a grid roller, intended to compact the surface of the fill, significantly increased surface erosion rates for all of the embankment placement methods. On average, erosion increased from 9.2 (no rolling) to 28.9 (with rolling) metric tons per hectare per year.

See the General Erosion Research Summary for additional information.

BMP 119—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: riprapping (third alternative).

No references were found; see the General Erosion Research Summary for information on the stabilizing effect of ground cover.

BMP 120—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: benching (fourth alternative).

Hartsog and Gonsior 1973, South Fork Salmon River Drainage, Payette National Forest—Field investigations evaluated the construction and initial performance stages of a road designed to minimize environmental impacts. The authors discussed the potential advantages and disadvantages of cutslope terraces. Some engineers believe that terraces improve regeneration; the authors believed that terracing increases erosion and sedimentation. The long-term effects of terracing on the study road's cutslopes were not yet apparent when the report was written (p. 10).

Megahan and others 1983, Silver Creek Study Area, Boise National Forest—Long-term (45-year) cutslope erosion was positively correlated with original cutslope gradient (pp. 24, 25). The authors recommended constructing cutslopes at lower gradients on gentle terrain and using terraced slopes on steeper terrain (p. 27).

Boise State University, Department of Geology and Geophysics 1984, Silver Creek Study Area, Boise National Forest—Collection troughs were used to evaluate erosion from cutslopes with gradients ranging from 0.95:1 to 1.8:1 for 3 years after road construction. All of the treated cutslopes (dry seed, hydroseed, hydroseed plus terrace) had much lower erosion than untreated cutslopes. However, sample sizes for the hydroseed plus terrace treatment were small (p. 20).

For results of fillslope studies, see Megahan and others (1991), and Megahan and others (1992).

Megahan 1988, Silver Creek Study Area, Boise National Forest—Cutslope terracing reduced surface erosion by 86 percent (p. 344).

See the General Erosion Research Summary for additional information.

BMP 121—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: mulching (fifth alternative).

Ohlander 1964, Zena Creek Study Area, Payette National Forest—Sediment and vegetation were measured on fillslope erosion plots on southerly slopes in the year following road construction. All plots except the control were seeded and fertilized; six treatments were tested: chipped slash, one layer paper netting, three layers paper netting, asphalt binder with straw, surface holes, and control (p. 19).

The author divided the study into three stages. In the first stage, the surface treatments alone afforded slope protection. Sediment measurement in the spring following construction showed that the asphalt binder with straw treatment had the lowest sediment production (242 pounds per acre). Chipped slash had higher sediment yields (15,247 pounds per acre than the control, which yielded 12,463 pounds of sediment per acre (p. 29).

In the second stage, during the summer, the surface treatments and the new vegetative growth both provided erosion protection . The fall sediment measurement showed asphalt binder with straw, yielding 138 pounds of sediment per acre, was the second most effective treatment. The control plots averaged 3,346 pounds per acre for the fall measurement. The chipped slash treatment substantially reduced erosion compared to the control during this stage, yielding 740 pounds of sediment per acre (p. 29).

The third stage was the vegetative stage, when vegetation provided the most erosion control. Measurements in the fall following construction showed the second highest vegetation production (1,599 pounds per acre) on the plots with asphalt binder with straw. The control produced only 20 pounds of vegetation per acre. The chipped slash treatment produced 900 pounds of vegetation per acre (p. 29).

Bethlahmy and Kidd 1966, Bogus Basin Road, Boise National Forest—Eight fillslope treatments (p. 2) were tested in plot studies including various combinations of contour furrows, seed, fertilizer, holes, straw mulch, polymer emulsion, paper netting, jute netting, chicken wire netting, and straw mulch with asphalt emulsion. All plots except the control were seeded and fertilized. The plots were on the fillslope of a newly constructed road. The fillslope had a gradient of 80 percent and a southeast aspect. Six measurements were made over 11 months.

Treatments were placed in three general groups (p. 4): seed and fertilizer (Group A); seed, fertilizer, and mulch (Group B); seed, fertilizer, mulch, and netting (Group C). In Group B, one plot had contour furrows, seed, fertilizer, holes, and straw mulch; the other plot had straw mulch with polymer emulsion, seed, and fertilizer (p. 2). Both of these treatments had less cumulative erosion than the control, an average of 72 percent less. This was less erosion than Group A, but more than Group C (see the seeding rule above and the other suitable means rule below). The addition of straw mulch in Group B reduced erosion by an average of 74 percent compared to similar treatments in Group A that did not include mulch (p. 4).

Jensen and Finn 1966, Zena Creek Study Area, Payette National Forest—Watershed conditions were evaluated throughout the Zena Creek Study Area. The authors noted that most previous road stabilization attempts on decomposed granitic soils, including mulching, were unsuccessful. Complete stabilization of cuts and fills on decomposed granitic soils appeared infeasible for slopes exceeding 45 percent (p. 76).

Megahan 1974a, Deadwood River Road, Boise National Forest—Fillslope plot studies evaluated surface erosion control, growth, and survival associated with ponderosa pine, grass, and surface amendments. The potential of ponderosa pine to reduce mass erosion was discussed and assumed, although it was not tested in this study (pp. 2-3, 15). The roadfill was 11 years old when the plots were installed, and had been unsuccessfully seeded to grass at least twice before the study (p. 4). The fillslope had a southwest aspect, and a gradient of 70 to 75 percent (p. 4). Nine treatments plus a control (pp. 5-6) were evaluated for longer than 3 years (p. 7).

Erosion did not differ significantly among the various treatments that used straw mulch (p. 13), which included treatments of seeded grass, seeded trees with and without fertilizer, and planted trees at two spacings, with and without fertilizer. All of the mulches were used in conjunction with erosion net (p. 5). Erosion on the mulched plots averaged 95 percent less than that on the control plots over a 3-year period. Effectiveness decreased somewhat over time; erosion reductions (relative to the control) fell from 98 percent in the first year to 92 percent in the third year. Mulches also increased tree growth on some plots (p. 13).

King 1979, Horse Creek Study Area, Nez Perce National Forest—Fillslope erosion was measured for 1 year after construction on three roads. Rill and gully erosion were dominant in the summer; slumping was important during spring snowmelt (p. 11).

On two roads, fillslopes were seeded and mulched (straw mulch with asphalt tackifier). These roads had average erosion volumes of 6.1 and 5.1 cubic feet per 100 feet of road as measured in a survey of rills and gullies. Measured volumes displaced by slumping were 21.91 and 13.57 cubic feet per 100 feet of road; however, not all of this material left the fill (p. 10).

No data on untreated fills were included. However, comparisons are available for one road with hydroseeded but unmulched fills. Erosion volumes estimated from measurements of rills and gullies were 9.9 cubic feet per hundred feet of road (p. 11). Slump surveys showed the volume of displaced material averaged 4.36 cubic feet per 100 feet of road (p. 10).

See other Horse Creek publications under this rule for followup reports.

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—Class 1 cutslopes (0 to 10 feet high) that were hydroseeded and mulched (straw mulch with an asphalt tackifier) showed significantly less erosion (73 percent reduction) than untreated cutslopes for the first year after construction. Cumulative erosion was 15 cubic feet per 100 feet of road for untreated cutslopes, compared to just 4 cubic feet for treated cutslopes (p. 21).

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Cook and King 1983, Horse Creek Study Area, Nez Perce National Forest—Erosion was evaluated for a 3-year period after construction on 1.5:1 road fillslopes that had been seeded, hydromulched, and fertilized. Average erosion measured in collection troughs below the fills was 35.85 cubic feet per 100 feet of road for Class 1 fillslopes (0 to 10 feet long) and 64.30 cubic feet per 100 feet of road for Class 2 fillslopes (10 to 20 feet long) (p. 3). No measurements were made on untreated fillslopes, so erosion protection provided by the treatment cannot be evaluated.

King 1984, Horse Creek Study Area, Nez Perce National Forest—Three treatments (plus a control) on cut and fillslopes were evaluated for 3 years after road construction. The treatments included: straw mulch with asphalt tackifier, seed, and fertilizer; cellulose fiber hydromulch, seed, and fertilizer; dry seeding; and no treatment.

On cutslopes, only the straw mulch treatment significantly reduced erosion, by 32 to 47 percent (p. 2). All of the treatments were comparable in reducing fillslope erosion. Relative to the control, the treatments reduced erosion by 24 to 30 percent for fills 20 to 40 feet high, and 46 to 58 percent for fills less than 20 feet high (p. 2).

See other Horse Creek reports under this rule for further information.

Burroughs and King 1985, Horse Creek Study Area, Nez Perce National Forest—Simulated rainfall was applied to 1.5:1 (67 percent) fillslopes to evaluate the relative erosion control effectiveness of an established dense stand of grass and wood excelsior mulch with nylon netting over loose soil, compared to loose soil. The grass stand had 97 percent cover of grass, litter, and stones greater than 0.25 inches in diameter; species were primarily orchardgrass and smooth brome. Four applications of simulated rainfall were made for each treatment (pp. 186-187). The grass treatment reduced sediment by 99.5 percent, and the mulch treatment reduced sediment by 91 percent, compared to the bare loose soil (p. 189). Mulch can be used to provide immediate protection, while a dense stand of grass provides effective long-term protection (p. 189).

Burroughs and King 1989, literature review, various sites—The authors review road erosion studies from Idaho and elsewhere. Only new Idaho data (not summarized elsewhere in this report), general observations, and recommendations will be included in this summary.

Erosion control treatments on one part of the road prism may influence sediment yield from other parts of the road prism (p. 1). Sediment contributions from the road prism components may vary over time. At one stream crossing in the Horse Creek Study Area, 80 percent of the sediment measured the first year after construction entered from the fillslope side of the road; by the fourth year, 83 percent was entering by the ditch system. The road tread was unsurfaced and crowned; cuts and fills were not treated (pp. 15-16).

Factors influencing the effectiveness of fillslope treatments include: timing, type, and rate of application of treatments, as well as insloping or outsloping of the road surface, soil erodibility, and slope gradient (p. 2). Many of the same variables influence cutslope erosion control, although erosion processes may be different on steep cutslopes (p. 11). Aspect, elevation, soil type, and frost heaving may be of importance (p. 12). Ditch maintenance may initiate cutslope erosion processes by undercutting the slope (pp. 12-13).

Effectiveness of fillslope mulches can be reduced by frost heaving or ground ice (p. 2). Hydromulches often do not remain on steep fillslopes unless combined with a fiber tackifier (p. 2). Drainage from the road tread onto the fillslope can reduce the effectiveness of any mulch (p. 3).

Wood chips and rock mulches cannot be used on cutslopes; hydromulch is ineffective on steep cutslopes (pp. 11, 12). Sediment reductions for hydromulching are estimated at 10 percent on 0.75:1 cutslopes, and 30 percent for 1:1 cutslopes or cutslopes that are not as steep (p. 12). Straw mulch is more effective if applied with a tackifier (p. 11). Estimated sediment reductions for straw mulch alone are 35 percent for 0.75:1 slopes and 40 percent for 1:1 slopes. For straw mulch with asphalt tackifier, the estimated sediment reductions are 40 percent for 0.75:1 and 75 percent for 1:1 slopes (p. 11). Frost heaving or ground ice can reduce effectiveness of cutslope mulch treatments (p. 11).

Megahan and others 1992, (Silver Creek Study Area, Boise National Forest—Erosion plots were used to evaluate the effectiveness of six construction techniques and 16 postconstruction treatments in controlling fillslope erosion for 3 years following road construction. Fills had design slopes of 1.5:1 or 1.33:1.

The most effective treatment, reducing erosion by 95 percent, was straw-crimp-seed-fertilizer-transplant. The straw-crimp-net treatment was the second most effective, reducing erosion by 93 percent. Other treatments with mulches that reduced erosion were: straw-polymer-seed-fertilizer-transplant (86 percent), straw-net-seed-fertilizer-transplant (83 percent), straw-net (79 percent), hydromulch-seed-fertilizer-transplants (69 percent), and hydromulch-seed-fertilizer (71 percent). The straw-crimp, hydromulch, and straw-polymer treatments were not significantly different from the control.

The 16 treatments were also divided into three groups that were tested for erosion control effectiveness: revegetation alone, surface amendments alone, and revegetation combined with surface amendments. Treatments in which revegetation and surface amendments were combined were the most effective, followed by revegetation alone, and surface amendments alone.

See the seeding rule, BMP 117; the other suitable means rule, BMP 122. See also the General Erosion Research Summary.

BMP 122—Rule 4.c.iii. Where exposed material (excavation, embankment, borrow pits, waste piles, and so forth) is potentially erodible, and where sediments would enter streams, stabilize prior to fall or spring runoff by: other suitable means (sixth alternative).

Ohlander 1964, Zena Creek Study Area, Payette National Forest—Sediment and vegetation were measured on fillslope erosion plots on southerly slopes in the year following road construction. All plots except the control were seeded and fertilized; six treatments were tested: chipped slash, one layer paper netting, three layers paper netting, asphalt binder with straw, surface holes, and control (p. 19).

The author divided the study into three stages. In the first stage, the surface treatments alone afforded slope protection. Sediment measurement in the spring following construction showed that the surface hole treatment, yielding 11,978 pounds per acre, produced only slightly less sediment than the control, which yielded 12,463 pounds per acre. In this stage, one layer of paper netting had reduced sediment yields (302 pounds per acre); however, three layers of paper netting had higher sediment yields (17,908 pounds per acre) than the control (p. 29).

In the second stage, during the summer, the surface treatments and the new vegetative growth both provided erosion protection. The fall measurement showed that the surface hole treatment (2,274 pounds per acre) reduced sediment yields compared to the control plots (3,346 pounds per acre). However, all other treatments were much more effective at this stage. The one layer of paper netting treatment produced just 128 pounds of sediment per acre. The three layers of paper netting treatment yielded 320 pounds per acre (p. 29).

The third stage was the vegetative stage, when vegetation provided the most erosion control. Measurements in the fall following construction showed the surface hole treatment produced 1,264 pounds of vegetation per acre; the control produced just 20 pounds per acre. The highest vegetation production was on the plots with one layer of paper netting (2,039 pounds per acre); plots with three layers of paper netting produced 1,341 pounds of vegetation per acre (p. 29).

Bethlahmy and Kidd 1966, Bogus Basin Road, Boise National Forest—Eight fillslope treatments (p. 2) were tested in plot studies including various combinations of contour furrows, seed, fertilizer, holes, straw mulch, polymer emulsion, paper netting, jute netting, chicken wire netting, and straw mulch with asphalt emulsion. All plots except the control were seeded and fertilized. The plots were on the fillslope of a newly constructed road. The fillslope had a gradient of 80 percent and a southeast aspect. Six measurements were made over 11 months.

Treatments were placed in three general groups: seed and fertilizer (Group A); seed, fertilizer, and mulch (Group B); seed, fertilizer, mulch, and netting (Group C). In Group C, one plot had seed, fertilizer, straw mulch, and paper netting; another plot had seed, fertilizer, straw mulch, and jute netting; and the last plot had seed, fertilizer, straw mulch, and chicken wire netting (p. 2). These treatments had much less cumulative erosion than the control, an average of 99 percent less. This was better than either group A or group B. See seeding and mulching rules as mentioned earlier. The addition of netting in Group C to the mulch treatments in Group B reduced average erosion by 98 percent.

Jensen and Finn 1966, Zena Creek Study Area, Payette National Forest—Watershed conditions were evaluated throughout the Zena Creek Study Area. The authors noted that most previous road stabilization attempts on decomposed granitic soils, including wattling (staking bundles of woody plant material, often live shrub cuttings that will root, into contour trenches and backfilling with soil) and artificial structures, were unsuccessful. Complete stabilization of cuts and fills on decomposed granitic soils appeared infeasible for slopes exceeding 45 percent (p. 76).

Megahan 1974a, Deadwood River Road, Boise National Forest—Fillslope plot studies evaluated surface erosion control, growth, and survival associated with ponderosa pine, grass, and surface amendments. The potential of ponderosa pine to reduce mass erosion was discussed and assumed, although it was not tested in this study (pp. 2-3, 15). The roadfill was 11 years old when the plots were installed, and had been unsuccessfully seeded to grass at least twice before the study (p. 4). The fillslope had a southwest aspect, and a gradient of 70 to 75 percent (p. 4). Nine treatments plus a control (pp. 5-6) were evaluated for longer that 3 years (p. 7).

Survival was poor for seeded grass and seeded trees, but excellent for planted trees (p. 8). After 4 years, 5 percent of seeded trees survived, compared to 97 percent of planted trees. Seeded grass decreased from 17.2 to 0.8 plants per square foot over the four 4-year period. Grass vigor may have decreased due to a severe grasshopper infestation (p. 8). Growth of planted trees was significantly greater in the upper fourth of the 200-foot-long fillslope (p. 11).

There was no significant difference in erosion between the two spacings (1.5 by 1.5 feet, and 2.5 by 2.5 feet) of planted, unmulched trees (p. 13). Planted trees without mulch significantly reduced erosion (compared to the control plots) each of the 3 years; average reductions were 44 percent (pp. 13-14).

Erosion did not differ significantly among the various treatments with mulch (p. 13), which included treatments of seeded grass, seeded trees with and without fertilizer, and planted trees at two spacings with and without fertilizer. All of the mulches were used in conjunction with erosion net (p. 5). Erosion on the mulched plots averaged 95 percent less than that on the control plots over a 3-year period. Effectiveness decreased somewhat over time; erosion reductions (relative to the control) fell from 98 percent in the first year to 92 percent in the third year. Mulches also increased tree growth on some plots (p. 13).

The author recommended that in areas where ponderosa pine is a climax or seral species, it should be planted on roadfills at 3- or 4-foot spacing, fertilized, and mulched for the maximum surface and mass erosion control benefits. Lodgepole pine was recommended for subalpine fir habitat types (pp. 15-16).

See Megahan (1978) for another report on this study.

Megahan 1978, Deadwood River Road, Boise National Forest—Fillslope plot studies evaluated surface erosion processes on bare plots and unmulched plots planted with ponderosa pine seedlings (p. 351). The roadfill had a southwest aspect, and a gradient of 70 to 75 percent; it was 11 years old when the plots were installed (p. 350).

Three water years (October 1 through September 30) of data were available to test seasonal differences (p. 351). Mean daily erosion was significantly greater during the summer-fall period than during the winter-spring period when there was no snow cover (pp. 351-352). Planted trees caused statistically significant reductions (0.05 level) in erosion during the summer-fall periods, but not during the winter-spring periods (p. 352). Within the summer-fall periods, plots with planted trees had significantly less (0.01 level) erosion than the control plots both during periods with rain and without rain (p. 353). Tree planting reduced estimated dry creep erosion (relative to the control) from 1.9 to 1.2 metric tons per square kilometer per day during rainy periods, and from 2.6 to 1.4 metric tons per square kilometer per day during rainfree periods (p. 355).

See Megahan (1974a) for other results of this study.

King 1979, Horse Creek Study Area, Nez Perce National Forest—Fillslope erosion was measured for 1 year following construction on three roads. Rill and gully erosion processes were dominant in the summer; slumping was important during spring snowmelt (p. 11).

On two roads, fillslopes were seeded and mulched (straw mulch with asphalt tackifier). These had average volumes of 6.1 and 5.1 cubic feet per 100 feet of road as measured in a survey of rills and gullies. Measured volumes displaced by slumping were 21.91 and 13.57 cubic feet per 100 feet of road; however, not all of this material left the fill (p. 10).

No data on untreated fills were included. However, comparisons are available for one road with hydroseeded but unmulched fills. Erosion volumes estimated from measurements of rills and gullies were 9.9 cubic feet per 100 feet of road (p. 11). Slump surveys showed an average of 4.36 cubic feet was displaced per 100 feet of road (p. 10).

See other Horse Creek publications listed under this rule for followup reports.

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—Class 1 cutslopes (0 to 10 feet high) that were hydroseeded and mulched (straw mulch with an asphalt tackifier) showed significantly less erosion (73 percent reduction) than untreated cutslopes for the first year after construction. Cumulative erosion was 15 cubic feet per 100 feet of road for untreated cutslopes, compared to 4 cubic feet for treated cutslopes (p. 21).

Carlton and others 1982, Gospel Hump management areas, Nez Perce National Forest—Fillslope erosion on roads constructed in 1978 and 1979 was evaluated by two methods from the spring of 1980 through the fall of 1981. The rill survey method was considered more representative of actual erosion rates than the bordered trap method (pp. 31, 38). All fillslopes were fertilized, seeded, and hydromulched (p. 13). Cumulative erosion volumes were about 65 cubic feet per 100 feet of road in the spring of 1980 and 85 cubic feet per 100 feet of road in the fall of 1981 (p. 30). No data were collected on untreated fillslopes, so erosion reduction due to treatment cannot be assessed.

Cook and King 1983, Horse Creek Study Area, Nez Perce National Forest—Erosion was evaluated for a 3-year period after construction on 1.5:1 road fillslopes that had been seeded, hydromulched, and fertilized. Average erosion measured in collection troughs below the fills was 35.85 and 64.30 cubic feet per 100 feet of road for Class 1 (0-10 feet long) and Class 2 (10-20 feet long) fillslopes, respectively (p. 3). No measurements were made on untreated fillslopes, so erosion protection provided by the treatment cannot be evaluated.

Boise State University, Department of Geology and Geophysics 1984, Silver Creek Study Area, Boise National Forest—Collection troughs were used to evaluate erosion from cutslopes with gradients ranging from 0.95:1 to 1.8:1 for 3 years after road construction. All of the treated cutslopes (dry seed, hydroseed, hydroseed plus terrace) had much lower erosion rates than untreated slopes. However, sample size for the hydroseed plus terrace treatment was small (p. 20).

For results of fillslope studies, see Megahan and others (1991) and Megahan and others (1992).

King 1984, Horse Creek Study Area, Nez Perce National Forest—Three treatments (plus a control) on cut and fillslopes were evaluated for 3 years after road construction. The treatments included: straw mulch with asphalt tackifier, seed, and fertilizer; cellulose fiber hydromulch, seed, and fertilizer; and dry seeding.

On cutslopes, only the straw mulch treatment significantly reduced erosion, by 32 to 47 percent (p. 2). All treatments were comparable in reducing fillslope erosion. Relative to the control, the treatments reduced erosion 24 to 30 percent for fills 20 to 40 feet high, and 46 to 58 percent for fills less than 20 feet high (p. 2).

See other Horse Creek reports in this rule for additional information.

Burroughs and King 1985, Horse Creek Study Area, Nez Perce National Forest—Simulated rainfall was applied to 1.5:1 (67 percent) fillslopes to evaluate the relative erosion control effectiveness of an established dense stand of grass and wood excelsior mulch with nylon netting over loose soil, compared to loose soil. The grass stand had 97 percent cover of grass, litter, and stones greater than 0.25 inches in diameter; species were primarily orchardgrass and smooth brome. Four applications of simulated rainfall were made for each treatment (pp. 186-187).

The grass treatments reduced sediment by 99.5 percent and the mulch treatment reduced sediment by 91 percent, compared to bare loose soil (p. 189). Mulch can be used to provide immediate protection, while a dense stand of grass provides effective long-term protection (p. 189).

Burroughs and King 1989, literature review, various sites—The authors reviewed road erosion studies from Idaho and elsewhere. Only new Idaho data (not summarized elsewhere in this report), general observations, and recommendations will be included in this summary.

Erosion control treatments on one part of the road prism may influence sediment yield from other parts of the road prism (p. 1). Sediment contributions from the road prism components may vary over time. At one stream crossing in the Horse Creek Study Area, 80 percent of the sediment measured the first year after construction entered from the fillslope side of the road; by the fourth year, 83 percent was entering by the ditch system. The road tread was unsurfaced and crowned; cuts and fills were not treated (pp. 15-16).

Factors influencing the effectiveness of fillslope treatments include: timing, type, and rate of application of treatments, as well as insloping or outsloping of the road surface, soil erodibility, and slope gradient (p. 2). Many of the same variables influence cutslope erosion control, although erosion processes may be different on steep cutslopes (p. 11). Aspect, elevation, soil type, and frost heaving may be important (p. 12). Ditch maintenance may initiate cutslope erosion processes by undercutting the slope (pp. 12-13).

Two types of erosion control nets (one plastic net, and one nylon-reinforced paper) were compared on 1:1 cutslopes with vertical heights of 8 to 12 feet in the Nez Perce National Forest. Two years of observations showed no displacement of the mats, and erosion reductions were estimated at 95 to 98 percent (p. 12). All mats and netting require uniform slopes to function properly (p. 12). Erosion reductions for excelsior mats is estimated as 75 percent on 1:1 cutslopes and 60 percent on 0.75:1 cutslopes (p. 12).

Megahan and others 1992, Silver Creek Study Area, Boise National Forest—Erosion plots were used to evaluate fillslope erosion control effectiveness of six construction techniques and 16 postconstruction treatments for 3 years after road construction. Fills had design slopes of 1.5:1 or 1.33:1.

Cost and effectiveness of the individual postconstruction treatments are given. The most effective treatment, reducing erosion by 95 percent, was straw-crimp-seed-fertilizer-transplant. The straw-crimp-net treatment was the second most effective, reducing erosion by 93 percent. The effectiveness of selected fillslope treatments are summarized:

Fillslope treatment	**Erosion reduction (percent change relative to control)**
Straw, crimp, seed, fertilizer, transplant	95
Straw, crimp, net	93
Straw, polymer, seed, fertilizer, transplant	86
Straw, net, seed, fertilizer, transplant	83
Steep slope seeder, transplant	81
Hydromulch, seed, fertilizer	71
Hydromulch, seed, fertilizer, transplants	69
Sprig, transplant	*
Polymer, seed, fertilizer, transplant	*
Sprig	*
Straw, crimp	*
Straw, polymer	*
Polymer	**

*Not significantly different from the control.
**Increased erosion 10 percent.

The 16 treatments were also divided into three groups that were tested for erosion control effectiveness: revegetation alone, surface amendments alone, and revegetation combined with surface amendments. The group of treatments that combined revegetation with surface amendments was the most effective, followed by revegetation alone, and surface amendments alone. See the seeding rule (BMP 117), compacting rule (BMP 118) mulch rule (BMP 121).

See the General Erosion Research Summary.

BMP 123—Rule 4.c.iv. In the construction of roadfills near streams, compact the material to reduce the entry of water, minimize erosion, and minimize the settling of fill material.

See summaries of Gonsior and Gardner (1971), Clayton and Arnold (1972), Hartsog and Gonsior (1973), and Megahan and others (1992), under BMP 118, stabilization of exposed material by compacting. See the General Erosion Research Summary for additional information.

BMP 124—Rule 4.c.iv. Minimize the amount of snow buried in embankments.

No references were found.

BMP 125—Rule 4.c.iv. Minimize the amount of ice buried in embankments.

No references were found.

BMP 126—Rule 4.c.iv. Minimize the amount of frozen soil buried in embankments.

No references were found.

BMP 127—Rule 4.c.iv. Avoid incorporating into fills significant amounts of woody material.

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—Extensive field and laboratory analyses were conducted, and slope stability was analyzed to determine the principal causes of slope failures in the Zena Creek Study Area. Based on these studies, the authors stressed that logs, stumps, large roots, and debris should always be removed from fill material (pp. 31, 32, 33).

BMP 128—Rule 4.c.iv. Slash may be windrowed along the toe of the fill, but must meet the requirements of Rule 4.d.iii.

BMP 129—Rule 4.c.iv. Debris may be windrowed along the toe of the fill, but must meet the requirements of Rule 4.d.iii.

Note: these two rules will be considered together since slash and debris are often incorporated into windrows, and since the terms may be used interchangeably in the literature.

Haupt 1959a,b, Little Owl Creek watershed of the Boise River basin—Haupt (1959b) looked at various road design and site factors as predictors of the distance sediment flowed below logging roads that had been "put to bed" (standard logging road closure techniques that include cross ditching and removal of temporary culverts) (pp. 329-330). Multiple regression analysis showed that the "slope obstruction index" was the variable most highly related to transport distance, followed by cross ditch interval squared, embankment slope length, and the product of cross ditch interval and road gradient (pp. 330-331). The lower sideslope gradient was not significant, because of the confounding effect of slope obstructions (p. 331). The regression equation (p. 332) can be used to predict necessary buffer strip widths under various conditions.

Haupt (1959a) used the regression equation to develop tables for use in road design, construction, and abandonment. Various tables can estimate the buffer strip widths, cross ditch interval, or slope obstruction index necessary to minimize sediment delivery to streams for a wide range of road and site characteristics (pp. 9-20).

Packer and Christensen 1964, based on research at 720 sites in Idaho and Montana—This publication is a field guide for controlling logging road sediment, primarily through the control of cross drain spacing and buffer strip widths. It is based on the research reported in Packer (1967) and field experience.

Slope obstructions vary in their ability to retard sediment flow. The following were listed in order of decreasing effectiveness (pp. 7, 9):

(1) Depressions made by pushed-over or wind-thrown trees, or a wavy ground surface
(2) Logs thicker than 4 inches
(3) Rocks more than 4 inches wide at ground surface
(4) Trees and stumps
(5) Slash and brush
(6) Grass, weeds, and shrubs.

A table (pp. 15-17) gives buffer strip widths (measured from the road centerline) required to prevent sediment delivery in 83 percent of cases, based on obstruction spacing and obstruction type. Adjustment factors are provided to allow for soil group, cross drain spacing, distance to first obstruction, fillslope cover density, and 97 percent prevention. For each 5-foot increase in distance to the first obstruction, the buffer strip width increases 4 feet.

Obstruction storage capacity tended to be exceeded by the fourth or fifth year after road construction. The authors suggested that buffer strips could be narrower if drainage is diverted toward other obstructions or if new obstructions are provided when the road is 3 years old (p. 11).

See Packer (1967) for additional information.

Packer 1967, 720 sites in Idaho and Montana, representing six major soil groups—Twenty-four watershed and road characteristics were tested as predictors of sediment movement downslope from logging roads. The significant variables, in their order of importance, were obstruction spacing, the interaction of obstruction type and spacing, undisturbed slope stability, cross drain spacing, initial obstruction distance, age of road, and fillslope cover density (pp. 12-13). The multiple regression equation (p. 12) is also represented in a table (pp. 16-17). This is essentially the same table as in Packer and Christensen (1964, pp. 15-17), except that distances are measured from the road shoulder rather than from the road centerline.

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—The authors conducted field and laboratory investigations of slope failures and soil properties. They recommended leaving riprap or debris at or near the toe of the fill to stop sediment movement (p. 33).

Megahan and Kidd 1972a, Zena Creek Study Area, Payette National Forest—Field observations showed substantially lower sediment yields from logging roads on one of three study watersheds. The reduction was due to interception of sediment flows by a barrier of logs and debris (pp. 5-6).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance of a road designed to minimize environmental impacts. Slash piled at the toe of the fills formed highly effective debris basins (p. 5). Most of the 165 cubic yards of sediment eroded from fills during a heavy 4-day storm was trapped in the slash and debris at the toe of the fills. Maximum transport distance was 300 feet (p. 18). The authors felt that the slash and debris piles were one of the best sediment control devices during the storm. They felt the piles should be used in the future unless the associated fire or insect hazard was too high (p. 20). They suggested that all fills should have sediment catchments, specifically slash and debris piles, if these are not esthetically unacceptable (pp. 21-22).

King1979, Horse Creek Study Area, Nez Perce National Forest—King evaluated travel distances for sediment flows from rill and gully erosion of roadfills for 1 year following road construction. Filter windrows were very effective in limiting material available for transport (0.22 cubic feet of eroded material per 100 feet of road length passed through the windrows, pp. 9-10).

See other Horse Creek reports listed under this rule for additional information.

King and Gonsior 1980, Horse Creek Study Area, Nez Perce National Forest—In one subdrainage, 550 feet of fillslopes (out of 731 feet) had filter windrows consisting of logging slash and debris, with cull logs keyed into the toe of the slope (p. 15). During the first summer, fall, and spring after construction, the windrows were 100 percent effective in retaining material eroded from the fillslope. Summer and fall fill erosion for the subdrainage was 25,000 to 40,000 pounds; spring fill erosion was 1,600 pounds. During the next summer-fall period, fill erosion in the subdrainage totalled 7,000 pounds. One windrow breach occurred, but no sediment reached the stream. The authors concluded that windrows were highly effective during the first year and a half (the period evaluated for this publication, p. 17).

Observations of roads constructed elsewhere during the same year supported this conclusion. Total windrow length was 1,220 feet. Both volumes and transport distances of sediment were reduced considerably below windrowed fills. Transport distances were 10 to 100 times greater below fills that were not windrowed (p. 17).

See other Horse Creek reports listed under this rule for additional information.

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—The authors compared erosion on sections of fillslopes that were windrowed or were not windrowed on one road for 2 years after construction. Differences were large, but not statistically significant. Sediment yields were 13.8 times greater on fills that were not windrowed for fillslopes 0 to 10 feet long and 70.2 times greater for fillslopes 10 to 20 feet long (pp. 15, 18).

Travel distances for sediment flows from rill and gully erosion of roadfills were evaluated for 2 years after road construction. No sediment was transported beyond fills with slash filter windrows the first year after construction; average sediment flow distance below windrows was 3.8 feet the second year after construction (p. 41). This is considerably less than the average distance for fills that were not windrowed (p. 42).

See other Horse Creek reports listed under this rule for additional information.

Cook and King 1983, Horse Creek Study Area, Nez Perce National Forest—Sediment volumes and transport distances below fills were evaluated for 3 years after road construction. All fills were 1.5:1 slopes, and were seeded, hydromulched, and fertilized. Some had slash filter windrows constructed at the toe of the fill. Windrow construction at five stream crossings had a total length of 1,190 feet (pp. 2-4).

Comparisons between windrowed fill sections and sections that were not windrowed in collection troughs below the fills indicated that 99 percent of eroded fill material was retained within the windrows (p. 3). The average volume of sediment collected in troughs below the windrows was 0.325 cubic feet per 100 feet of road for fill lengths of 0 to 10 feet, and 0.650 cubic feet per 100 feet of road for fill lengths of 10 to 20 feet. Corresponding values for fills that were not windrowed were 35.85 cubic feet per 100 feet of road (fill lengths of 0 to 10 feet) and 64.30 cubic feet per 100 feet of road (fill lengths of 10 to 20 feet, pp. 3-4). Surveys of rills and gullies in the fills provided another means of estimating windrow performance. Based on these data, the authors conservatively estimated that the windrows trapped 75 to 85 percent of the sediment (p. 4).

Only seven sediment flows were observed below the windrowed fills in the 3-year study period; three of these delivered sediment to the stream. If windrows were breached, it was usually because of slumping when snowmelt saturated the fill (p. 4). Average transport distance for sediment flows was 3.8 feet below windrows. For fills that were not windrowed, the average transport distance was 41.4 feet for flows originating in slumps, and 24.2 feet for flows originating in areas of the fill that had not slumped (p. 4).

See other Horse Creek reports listed under this rule for additional information.

Burroughs and King 1985, Horse Creek Study Area, Nez Perce National Forest—Simulated rainfall was applied to 1.5:1 (67 percent) fillslopes to evaluate the relative effectiveness of an established dense stand of grass, wood excelsior mulch with nylon netting over loose soil, or loose soil with a filter windrow, compared to loose soil. The grass stand had 97 percent cover of grass, litter, and stones greater than 0.25 inches in diameter; species were primarily orchardgrass and smooth brome. Four applications of simulated rainfall were made for each treatment (pp. 186-187). The grass treatment reduced sediment by 99.5 percent, mulch by 91 percent, and windrow by 87 percent, compared to bare loose soil (p. 189). This study indicates that windrows can provide effective protection immediately following construction; other observations in the study area confirmed that windrows were still effective 7 years after road construction (p. 190).

Burroughs and King 1989, Horse Creek Study Area and Gospel Hump management areas, Nez Perce National Forest—Most of these results have been summarized before.

The Horse Creek fillslope sediment data from one road were summarized for 2 years after construction (p. 9), showing the influence of slash filter windrows, road surface drainage, slumping, and culverts. Windrowed fills had the shortest average (3.8 feet) and maximum (33 feet) transport distances of the five categories. Material below windrows was often transported over the snowpack during the spring rather than through the windrow (p. 8).

The influence of obstruction density (rated on an index from 0 to 6, with 6 most dense) on sediment transport distance was reported for Gospel Hump (p. 9). Obstructions included slash, shrubs, depressions, and so forth below the fills. Transport distance decreased as the obstruction index increased.

Ketcheson and Megahan 1990, Silver Creek Study Area, Boise National Forest—The volumes and lengths of sediment flows below roads were measured for 4 years after road construction. Sediment flows from fills traveled an average of 20 feet (p. 3); the maximum distance was less than 200 feet (p. 12). Sediment volume and the distance sediment traveled did not differ significantly between fills with and without cull logs placed at the toe (p. 3).

Obstructions can deflect or stop sediment flow if they are large, in good contact with the ground, and oriented perpendicular to the slope. Small stems are generally ineffective (p. 11).

See Burton (n.d.) for additional information.

Burton (n.d.), unpublished data attributed to Megahan, Silver Creek Study Area, Boise National Forest—Sediment storage behind obstructions and the lengths of sediment flow were strongly correlated (p. 2). An equation relating sediment flow travel distance to sideslope gradient, source area, total length of obstructions, and total volume of on-site erosion was derived (p. 3).

See Ketcheson and Megahan (1990) for additional information.

See the General Erosion Research Summary.

BMP 130—Rule 4.c.v. Construct stream channel crossings in compliance with minimum standards for stream channel alterations under the provisions of Title 42, Chapter 38, Idaho Code.

No references were found, other than those listed under the corresponding Forest Practices Act BMP's.

BMP 131—Rule 4.c.v. Avoid road construction in stream channels.

See Rule 4.b.i., minimum road construction in stream protection zones and road buffer strip rules (BMP's 86 through 88) and Rule 4.b.vi., minimum stream crossings (BMP 106).

BMP 132—Rule 4.c.v. Construct roads that constrict upon a stream channel in compliance with minimum standards for stream channel alterations under provisions of Title 42, Chapter 38, Idaho Code.

No references were found, other than those listed under the corresponding Forest Practices Act BMP's.

BMP 133—Rule 4.c.vi. During and following operations on outsloped roads, retain outslope drainage.

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance of a road designed to minimize environmental impacts. The road was designed as an outsloped road, but skidded logs and skidding tractors created ruts in the road surface (p. 13). The authors felt that concentrations of water would occur on almost any outsloped road under normal traffic conditions (p. 20).

A berm left by a grading operation concentrated water that eventually drained onto the fillslope. During a heavy 4-day rainstorm, 165 cubic yards of fill material eroded (p. 18); the berm was the single most important factor contributing to erosion (p. 13).

Burroughs and King 1989, Horse Creek Study Area, Nez Perce National Forest—Sediment entering the stream by the ditch system (representing erosion of the cut, ditch, and 28 percent of the road surface) and that entering from the fillslope side (representing erosion of the fillslope and 72 percent of the road surface) was monitored for 4 years following construction on a crowned road section (p. 16). At the study site, the cut and fill had no erosion control treatment, and the road was unsurfaced (p. 15). A berm was created unintentionally during construction and maintenance activities. This berm concentrated drainage onto the fill and contributed to high fill erosion rates during the first year, when 80 percent of the sediment entered by the fillslope side of the road (p. 16).

The authors recommend insloping to the ditch or providing uniform distribution for outslope drainage. Outsloped sections would require careful road maintenance to avoid creating berms and to maintain uniform drainage (p. 16).

See Rule 4.b.iv., outsloping and insloping rules (BMP's 97 and 98).

BMP 134—Rule 4.c.vi. During and following operations on outsloped roads, remove berms on the outside edge except those intentionally constructed for protection of road grade fills.

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance stages of an outsloped road designed to minimize environmental impacts. A berm left by a grading operation concentrated water that eventually drained onto the fillslope. During a heavy 4-day rainstorm, 165 cubic yards of fill material eroded (p. 18); the berm was the single most important factor contributing to erosion (p. 13).

Megahan and others 1986, Silver Creek Study Area, Boise National Forest—Erosion and sediment were evaluated in three watersheds during road construction. During construction, erosion often depended more on the stage of road construction during rainstorms than on the final design features of the road. The authors recommended that temporary berms be constructed to protect fills when storm threats are high (p. 39).

Burroughs and King 1989, Horse Creek Study Area, Nez Perce National Forest—Sediment entering the stream by the ditch system (representing erosion of the cut, ditch, and 28 percent of the road surface) and that entering from the fillslope side (representing erosion of the fillslope and 72 percent of the road surface) was monitored for 4 years after construction on a crowned road section (p. 16). At the study site, the cut and fill had no erosion control treatment, and the road was unsurfaced (p. 15).

A berm was created unintentionally during construction and maintenance. The berm concentrated drainage onto the fill and contributed to high fill erosion rates during the first year, when 80 percent of the sediment entered from the fillslope side of the road (p. 16).

The authors recommend insloping to the ditch or providing uniform distribution for outslope drainage. Outsloped sections require careful road maintenance to avoid creating berms and to maintain uniform drainage (p. 16).

BMP 135—Rule 4.c.vii. Provide for drainage of quarries to prevent sediment from entering streams.

Bachmann 1958, Silver and Crystal Creeks, near Pierce—This study investigated the effects of logging and logging road construction on selected physical, chemical, and biological features of northern Idaho trout streams (pp. 2-3), using a paired-watershed approach (p. 9). Measured predisturbance (1955 and 1956) turbidities ranged from 0.25 to 2.10 parts per million in Silver Creek, and from 0.6 to 6.9 parts per million in Crystal Creek (p. 34).

Rock was quarried in the Crystal Creek watershed during road construction in 1956 and 1957 (p. 22). The quarry was adjacent to a small tributary, and was a major source of sediment (p. 30). Sediment deposits nearly covered the channel below the quarry. Turbidities at the sampling station near the quarry were among the highest measured in the study (p. 30). For example, turbidity ranged to 350 parts per million during snowmelt and to 2,169 parts per million after a 12-hour rain (p. 36). Turbidity sampling was not adequate to define average or maximum values (p. 37).

BMP 136—Rule 4.c.viii. Construct cross drains to minimize erosion of embankments.

Haupt and others 1963, Zena Creek Logging Study Area, Payette National Forest—Following three long-duration, low-intensity storms of unprecedented total rainfall (pp. 4-5), the erosion on insloped and outsloped road sections of a newly constructed logging road were compared visually. Both insloped and outsloped sections had earthen cross drains spaced 30 to 90 feet apart (p. 2). Shoulders and fills had been seeded and mulched with chopped hay and asphalt binder (p. 3).

All earthen cross drain outlets were deeply eroded on the outsloped portions (p. 6). Cross drains also generated fill erosion on insloped sections. Cross drain outlets were the only site where surface drainage overtopped the inslope (p. 7). Based on their observations, the authors recommended that if earthen cross drains are to be used, they should drain on the outcurve (p. 8).

See Rule 4.b.iv., dips/water bars/cross drain rules (BMP's 100 through 102); Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122); and the General Erosion Research Summary.

BMP 137—Rule 4.c.viii. Construct relief culverts to minimize erosion of embankments.

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—During the authors investigations of slope failures in the Idaho Batholith, low soil permeablilities were measured. Permeability can be expected to decrease over time in roadfills and elsewhere; this must be considered when designing culverts (p. 12). The authors stress the need to evaluate surface and subsurface flow water conditions when locating and designing roads (p. 33).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—A road designed to minimize watershed impacts was evaluated during the construction period and the early period of use. The authors recommended against using dimpled connecting bands on culverts to avoid leakage and to prevent sections from separating. They also recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10). Proper bedding of culverts and compaction of backfill material are discussed (p. 12).

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—Travel distances for sediment flows from rill and gully erosion of roadfills were evaluated for 2 years after road construction. Flows influenced by relief culverts (the source gully was below or adjacent to culverts) tended to travel farther (pp. 41-42).

See Burroughs and King (1989) for additional information.

Burroughs and King 1989, Horse Creek Study Area and Rainy Day Road, Nez Perce National Forest—In the Horse Creek Study Area, rill volumes and sediment flow transport distances were measured for 2 years after road construction. One of the longest average transport distances (72.8 feet) for sediment flows below road fillslopes resulted when rills formed below relief culvert outflows or when sediment flows from rills combined with the paths of relief culvert flows (pp. 8-9). Transport distances below relief culverts were not strongly correlated with the length of road contributing to the culvert, the road gradient, or the sideslope gradient (p. 10). The authors developed a cumulative frequency distribution of sediment travel distances for flows influenced by relief culverts (p. 10); this might apply to similar sites with gneiss and schist parent material and sideslope gradients of 30 to 40 percent (p. 11).

See Tennyson and others (1981) for additional information.

See Rule 4.b.v., relief culvert rule (BMP 103) and culvert installation rule (BMP 104); Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122); and the General Erosion Research Summary for additional information.

BMP 138—Rule 4.c.viii. Minimize the time between construction and installation of erosion control devices.

No references were found that directly address time trends in fill erosion due to outflow from drainage structures. However, numerous studies show time trends that illustrate the need for timely application of erosion control measures. For examples of time trends ranging from days to years see: Ohlander (1964), p. 29; Bethlahmy and Kidd (1966), p. 4; Megahan (1978), pp. 352-353; Carlton and others (1982), p. 30; Cook and King (1983), p. 4; Megahan and others (1992), p. 64.

BMP 139—Rule 4.c.viii. Use riprap to minimize erosion of the fill.

No references were found; see the General Erosion Research Summary.

BMP 140—Rule 4.c.viii. Use vegetative matter to minimize erosion of the fill.

No references were found. See Rule 4.c.iii., stabilization of exposed material by seeding (BMP 117), mulching (BMP 121), and other suitable means (BMP 122); and the General Erosion Research Summary.

BMP 141—Rule 4.c.viii. Use downspouts to minimize erosion of the fill.

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—A road designed to minimize watershed impacts was evaluated during the construction period and the early period of use. Based on their observations, the authors recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10).

BMP 142—Rule 4.c.viii. Use similar devices [similar to downspouts] to minimize erosion of the fill.

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—A road designed to minimize watershed impacts was evaluated during the construction period and the early period of use. Based on their observations, the authors recommended skewing culverts or using downspouts to avoid steep culvert gradients that result in scour (p. 10).

See Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122), and the General Erosion Research Summary.

BMP 143—Rule 4.c.viii. Install drainage structures on incomplete roads that are subject to erosion prior to fall or spring runoff (first alternative).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—Field investigations evaluated the construction and initial performance stages of a road designed to minimize environmental impacts. The road was designed as an outsloped road, but skidded logs and skidding tractors created ruts in the road surface (p. 13). During a heavy

4-day rainstorm on Labor Day weekend, this road had considerable erosion, which was largely attributed to incomplete shaping and grading (p. 19). A half-mile length of pioneer road had no erosion, even though it had no drainage structures installed. This was attributed to minimal disturbance of natural drainage patterns, flat grade or short stretches of unbroken grade, and loose, absorbent soil conditions (p. 15). The authors suggested that the best solution might be to construct a minimum standard contour road with a rolling grade, including drainage structures, during logging operations. Each road section could then be completed to the desired standard when log hauling was finished on that section (p. 19).

Megahan and others 1986, Silver Creek Study Area, Boise National Forest—Erosion and sediment were evaluated in three watersheds during road construction. Erosion during construction often depended more on the stage of road construction during rainstorms than on the final design features of the road. The authors recommended that temporary berms be constructed to protect fills when storm threats are high (p. 39).

No references were found that dealt directly with erosion due to lack of drainage structures on incomplete roads during spring and fall runoff. However, many references have implications for this rule. See Rule 4.c.viii., time between construction and installation of erosion control devices (BMP 138). References listed there show fill erosion time trends. See Megahan and Kidd (1972a, p. 8) for seasonal and annual time trends in total road erosion. In the General Erosion Research Summary, see Burroughs and others (1972), regarding spring runoff; Megahan (1972), regarding spring runoff; Megahan (1974b), regarding road erosion time trends; Vincent (1985), regarding seasonal runoff and sedimentation from road tread; and Ketcheson and Megahan (1990), regarding seasonal and annual trends in total road erosion.

BMP 144—Rule 4.c.viii. Install cross drains on incomplete roads that are subject to erosion prior to fall or spring runoff (second alternative).

No references were found that directly address this rule; see Rule 4.c.viii., drainage structures for incomplete roads subject to erosion (BMP 143); and Rule 4.b.iv., cross drain rules (BMP's 100 through 102).

BMP 145—Rule 4.c.viii. Install relief culverts with a minimum grade of 1 percent.

No references were found.

BMP 146—Rule 4.c.ix. Postpone earthwork during wet periods, if, as a result, erodible material would enter streams.

No references were found that directly address earthwork during wet periods; however, the following studies have some implications for this rule.

Burroughs and others 1983b, Rainy Day Road, Nez Perce National Forest—Simulated rainfall was applied repeatedly to new road prism surfaces (cut, tread, and ditch). Initial sediment yields on the unprotected surfaces were high but yields declined rapidly (p. 9). Sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields also decreased rapidly with successive applications of simulated rainfall (p. 16). However, the rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22).

Foltz and Burroughs 1990, Tin Cup Creek, Caribou National Forest, east of Idaho Falls—Three 30-minute applications of simulated rainfall were applied to paired roadway surface plots, one rutted and one unrutted. There was a thin layer of loose material over a compacted, bladed road surface (p. 272); gradients of the plots were 8.4 and 9.0 percent (p. 269). Sediment production from the rutted plots decreased sharply over time after the first 20 minutes, reflecting a limited supply of material for transport (p. 272). Sediment production from the unrutted plots rose for about the first 30 minutes, but then maintained a more level sediment production with a slight decline at about 45 minutes. The sediment levels from the rutted plot were consistently higher than those from the unrutted plot, peaking at 90 grams per second, compared to 32 grams per second for the unrutted plot (p. 272). When the data were adjusted to account for the relative proportions of rutted and unrutted surface on a road with two ruts, the sediment production ratios were 2.1 (dry conditions), 1.2 (wet conditions), and 1.0 (very wet conditions); the different conditions correspond to the measurements during the three applications of simulated rainfall (pp. 273-274). Road closures and other measures are recommended to prevent rutting during wet weather (p. 275).

Megahan and others 1991, Silver Creek Study Area, Boise National Forest—Several site factors were tested as predictors of fillslope erosion during snowfree periods. Only ground cover density and rainfall erosivity were statistically significant (p. 56).

BMP 147—Rule 4.c.x. In rippable materials, construct roads with no overhanging banks.

No references were found.

BMP 148—Rule 4.c.x. In rippable materials, fell any trees that present a potential hazard to traffic concurrently with the construction operation.

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—Extensive field and laboratory analyses of slope failures were conducted. The authors felt that live trees were important sources of slope stability by mechanically reinforcing the soil and depleting moisture (and possibly slowing subsurface weathering by moderating temperatures). They recommended leaving barriers of live trees immediately below the fill and above the cut (pp. 31-32).

Burroughs and Thomas 1977, South Fork Payette River near Lowman, Boise National Forest—Rocky Mountain Douglas-fir root numbers and tensile strength over time were measured on clearcut and undisturbed slopes. All sampling areas were within old-growth sites (100- to 200-year-old trees). Tensile strength of tree roots was shown to be an important factor increasing slope stability on logged and unlogged slopes. However, root strength decreases rapidly in the first year after tree felling, continuing to decrease gradually over time (p. 16).

Megahan and others 1979, Clearwater National Forest and Middle Fork Payette River drainage, Boise National Forest—In the two study areas, 1,418 landslides were inventoried (p. 121). The frequency of landslides tended to increase as either tree or shrub crown cover decreased (p. 132). When crown covers were less than 80 percent, landslide occurrence appeared to be more sensitive to reductions in shrub crown cover than to reductions in tree crown cover. The authors recommended using timber harvest procedures that minimize the disturbance of understory vegetation (p. 132). Landslides were most common 4 to 10 years after logging; landslide frequencies remained elevated for 20 years after logging (p. 133). These time trends were attributed to the loss of root strength through decay (increasing landslide frequency), interacting with growth of new roots (decreasing landslide frequency) (p. 132).

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River drainage, Boise National Forest—Several analyses evaluated the contributions of forest vegetation to slope stability through various mechanisms. The analyses showed that many sites in the Idaho Batholith are in a state of marginal equilibrium, and may fail when roads are constructed or trees are harvested (p. 20). The authors recommended leaving buffer zones of trees above and below haul roads, although they noted that the benefits of leaving trees must be weighed against the safety hazards they represent (p. 21).

Megahan and others 1983, Silver Creek Study Area, Boise National Forest—Long-term (45-year) cutslope erosion was estimated using exposed tree roots. Reductions in soil erosion due to tree roots were observed in the field and were also apparent from the data. The authors indicate that this benefit should be considered when deciding whether to cut trees above road cutslopes (p. 27).

Megahan and Bohn 1989, Silver Creek Study Area, Boise National Forest—Three progressive mass failures (sapping failures) were monitored after logging and road construction. This type of failure had never been observed previously in the study area. Two of the failures occurred at low gradient sites (9 and 11 percent) in cutting units and were attributed to changes in seepage flows due to logging (p. 508). The other failure originated in a road cutslope and was attributed to the steepness (34 percent) of the cutslope (p. 508). Mass erosion hazards in the cutslope are increased if timber is harvested above the roadcut (p. 509). Tree roots were observed to slow the uphill progress of failure and to retain soil that would otherwise collapse (pp. 504, 506).

See the General Erosion Research Summary for additional information.

Rule 4.d. Road Maintenance

Forty BMP's (149 through 188) were evaluated. Best management practices 149 and 150 comprise the general rule 4.d.: "Conduct regular preventive maintenance operations to avoid deterioration of the road surface and minimize disturbance and damage to forest productivity, water quality, and fish and wildlife habitat." The remaining BMP's addressed several specific topics associated with road maintenance:

- Disposition of maintenance products (BMP's 151 and 152)
- Repair and stabilization of slumps, slides, and similar failures (BMP's 153 through 158)
- Maintenance of culverts and ditches (BMP's 159, 160, 170, 171, 177, 184, 188)
- Controlling road surface drainage through crowning, outsloping, insloping, water barring, berm removal, and similar practices (BMP's 161 through 165, 172 through 176, 180 through 181)
- Maintenance of the road surface (BMP's 166 through 169)
- Road closures (BMP's 178, 179, 185)
- Seeding and other erosion control measures on abandoned roads (BMP's 182 and 183)
- Bridge removal on abandoned roads (BMP 186)
- Culvert removal on abandoned roads (BMP 187).

Disposition of Maintenance Products

No references were found on this topic.

Repair and Stabilization of Slumps, Slides, and Similar Failures

In the Horse Creek Study Area, Burroughs and King (1989, pp. 8-9) measured sediment flow transport from rills and gullies on fillslopes for 2 years after road construction. The longest average transport distance, 80.4 feet, was for sediment flows from rills formed in slumped material (pp. 8-9). Megahan and others (1979) inventoried landslides on the Clearwater and Boise

National Forests. On average, 19 percent of the slide material was delivered to a stream (p. 121). Costs of road repair and slide stabilization were estimated for the Clearwater slides (p. 135).

Maintenance of Culverts and Ditches

No references were found on maintenance of culverts. Three references alluded to the role of ditch maintenance in perpetuating cutslope erosion. Arnold and Lundeen (1968, p. 117) surveyed road erosion on the roads producing the most sediment in the South Fork Salmon River drainage. They estimated that 10 percent of sediment originated from cutslopes and ditches; 21 percent originated from maintenance wasting of cutslope material. Megahan and others (1983, p. 28) noted that road maintenance is the primary cause of long-term accelerated cutslope erosion. Removal of slough material at the base of the roadcut during maintenance operations interferes with the natural slope-forming process, removes a favorable site for vegetation growth, and reinitiates slope erosion processes. They suggested that removal of the material deposited at the base of the roadcut be avoided or minimized whenever possible, for instance, on forest roads that are used infrequently. Similarly, Burroughs and King (1989, pp. 12-13) observed that ditch maintenance often undercuts the cutslope, reinitiating cutslope erosion processes.

Controlling Road Surface Drainage Through Crowning, Outsloping, Insloping, Water Barring, Berm Removal, and Similar Practices

No references were found on crowning. Research on all the other methods was reviewed under Rule 4.b. or Rule 4.c.; the corresponding BMP's under those rules are cross-referenced. For outsloping and insloping, refer to Rule 4.b.iv., outsloping and insloping rules (BMP's 97 and 98). For water bars, refer to Rule 4.b.iv., dips, water bars, and cross drains (BMP's 100 through 102). For berm removal, refer to Rule 4.c.vi., berm removal (BMP 134).

Maintenance of the Road Surface

Packer and Christensen (1964, p. 2) noted that research indicated secondary logging road surfaces deteriorate rapidly when rill depths exceed 1 inch. Packer (1967) tested 14 road and watershed variables as predictors of the surface water flow distance producing 1-inch rills. The multiple regression equation developed from the most important predictive variables was used to make a table (Packer 1967, p. 11; Packer and Christensen 1964, pp. 13-15) that gives recommended cross drain spacings (to prevent 1-inch rill formation) by road grade and soil type, with adjustments for topographic position, aspect, slope steepness, and the percent of cases in which 1-inch rill formation is to be prevented.

In Packer's analysis (1967, pp. 8-9) the most important predictive variable was the proportion of soil particles and water-stable aggregates larger than 2 mm on the road surface. Although this property is related to the soil group, the benefits of larger particles can be derived on all soil types by surfacing roads with gravel or crushed rock. Similarly, in tests with simulated rainfall on various road surface types, Burroughs and others (1983a, p. 10) found that sediment yield was correlated directly with the amount of loose soil on the surface, and inversely correlated with the average size of the loose soil. A later publication on the same study (Burroughs and King 1985, p. 187) reported that sediment yields from dust oil surfaces were about 13 percent of the yield from the native surfaces at the same gradient,and that yields from bituminous surfaces were just 1.1 percent of those from native surfaces. However, Burroughs and King (1989, p. 2) noted that dust oil surfaces break down under heavy traffic and also contribute volatile chemicals to surface runoff. Another simulated rainfall experiment (Burroughs and others 1983b, p. 1) indicated that a travelway (road tread) with gravel surfacing produced only 23 percent of the sediment yield of an unsurfaced travelway. The same study also indicated that rocked ditches generated less sediment than unrocked ditches.

Burroughs and King (1989) summarized research results from Horse Creek and Gospel Hump. In both cases, sediment transport distances below fills were generally larger for sediment flows influenced by travelway drainage (p. 9).

Two studies with simulated rainfall indicated that rutted roads produce higher sediment yields than unrutted roads. Burroughs and others (1983b, p. 16) reported that sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields decreased rapidly with successive applications of simulated rainfall. However, the rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22). In eastern Idaho, Foltz and Burroughs (1990, pp. 273-274) found that sediment yields on rutted roads were 1.0 to 2.1 times yields on unrutted roads, with the ratio depending on the moisture conditions before the simulated rainfall.

Megahan (1974b) developed a negative exponential equation showing surface erosion on severely disturbed granitic soils over time. By far the greatest percentage of erosion occurs in the first and second years after construction (p. 12). Additional disturbances (such as road grading) result in new cycles of surface erosion (p. 13). This was supported by Vincent's (1985) study of road surface sediment production in the Silver Creek Study Area. The study road was constructed in 1980, extensively eroded before the first measurements in 1981, and regraded before the 1982 measurements (pp. 7-9). The road was less erodible in the eroded condition than in the regraded condition; a given amount of runoff generated 75 to 80 percent less sediment for the eroded road in 1981 than for the regraded road in 1982 (p. 39), a reversal of the usual time trend.

Megahan (1988, p. 341) stated that long-term accelerated erosion tends to continue on roads in direct proportion to traffic use and in inverse proportion to the level of road maintenance. Megahan and others (1983, p. 28) noted that road maintenance is the primary cause of long-term accelerated cutslope erosion. Removal of slough material at the base of the roadcut during maintenance operations interferes with the natural slope-forming process, removes a favorable site for vegetation growth, and initiates slope erosion processes. They suggested that removal of the material deposited at the base of the roadcut should be avoided or minimized whenever possible, on forest roads that are used infrequently, for instance. Arnold and Lundeen (1968, p. 117) surveyed road erosion on the roads producing the most sediment in the South Fork Salmon River drainage. They estimated that 21 percent of sediment originated from maintenance wasting of cutslope material, and that just 4 percent originated from road surfaces.

Road Closures

Megahan (1988, p. 341) stated that long-term accelerated erosion tends to continue on roads in direct proportion to traffic use.

In the South Fork Salmon River drainage, closed roads were inventoried to evaluate surface and mass erosion. Roads with light use (foot, horse, or motorcycle) showed greater average surface erosion than those with no use (Clifton and Megahan 1988, p. 4).

Two studies with simulated rainfall indicated that rutted roads produce higher sediment yields than unrutted roads. Burroughs and others (1983b, p. 16) reported that sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields decreased rapidly with successive applications of simulated rainfall. However, they noted that the rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22). In eastern Idaho, Foltz and Burroughs (1990, pp. 273-274) found that sediment yields on rutted roads were 1.0 to 2.1 times yields on unrutted roads, with the ratio depending on the moisture conditions before the simulated rainfall. They recommended road closures to prevent rutting during wet weather (p. 275).

Seeding and Other Erosion Control Measures on Abandoned Roads

Haupt and Kidd (1965) monitored the effectiveness of various techniques designed to minimize erosion associated with logging and logging road construction. These included seeding, harrowing, and cross draining of roads following logging in 1953 and 1954 (p. 665). By 1958, the perennial grasses that had been seeded on the roadways were well established and erosion was negligible during the most intense storm (2.82 inches of rain per hour for 10 minutes) of the 7-year study period (p. 668).

Megahan and Kidd (1972a,b) studied erosion and sedimentation from logging and road construction. Roads built in October 1961 were seeded and water barred after logging was completed in November 1962. The average sedimentation rate in ephemeral drainages below roads for 4.8 years after logging was 51.0 tons per square mile per day. No data were collected for comparison on roads that were not seeded or water barred. Sedimentation rates on nearby undisturbed watersheds averaged 0.07 tons per square mile per day. A return to predisturbance levels was not expected due to continued roadcut and tread erosion.

In the South Fork Salmon River drainage, closed roads were inventoried to evaluate surface and mass erosion (Clifton and Megahan 1988). Erosion classes were used for surface erosion ratings, with 1 = natural, 2 = very low, 3 = low, 4 = moderate, and 5 = high (p. 2). Average values for roadfills and road tread were each slightly less than 2, while the average value for roadcuts was 2.6 (p. 3). On all road prism components (roadcut, road tread, and roadfill), correlation analyses showed that as ground cover densities increased, surface erosion decreased. Roadcuts were most sensitive to changes in cover density (p. 5). Ground cover included litter and rocks, as well as vegetative cover.

Because cutslopes exhibited the greatest erosion and were more sensitive to changes in cover, Clifton and Megahan (1988) recommended that cutslope revegetation be given priority for rehabilitation measures (p. 6).

Multiple regression analyses also were conducted for each component of the road prism. Of 19 variables tested, the roadcut cover density and bedrock weathering class explained 86 percent of the variance in roadcut surface erosion (p. 6). Of 40 variables tested, the roadfill cover density explained 69 percent of the variance in roadfill surface erosion (p. 7). Of 25 variables tested, the percent road tread cover outside wheel tracks explained 53 percent of the variance in road tread surface erosion (p. 6).

A followup report (Clifton and Thompson 1989) noted that 73 percent of the variation in surface erosion (for cut, tread, and fill combined) was explained by the cover density variable (p. 4). Ground cover included litter and rocks as well as vegetative cover. Average cover densities were 85 percent on roadcuts, 90 percent on road tread, and 91 percent on roadfills (p. 13).

See Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122) and the General Erosion Research Summary for additional information.

Bridge Removal on Abandoned Roads

No references were found on this topic.

Culvert Removal on Abandoned Roads

Jensen and Finn (1966, pp. 87, 90) described road rehabilitation in the Deep Creek drainage. Rehabilitation consisted of digging channels across the road to reopen ephemeral drainages, constructing dips every 100 feet, and removing all culverts and fill material in draws. The roadway was seeded to perennial grasses. The authors recommended using the same techniques in future rehabilitation efforts on decomposed granitic landtypes, using a dragline (if possible without major reconstruction) and a D-7 or D-8 tractor. They noted, however, that even with such efforts, it would be impossible to stop most of the accelerated sedimentation or to restore the natural hydrologic function that had been altered by roadcuts (p. 91).

In the South Fork Salmon River drainage, surface and mass erosion were evaluated on 13 closed logging roads about 20 years after they were closed (Clifton and Thompson 1989, p. 3). The authors identified problem sites with the potential to deliver sediment to streams, assigning values for the potential delivery to streams (1 = no potential through 9 = sediment supplied directly to the watercourse) and priority for treatment (1 = high priority through 9 = low priority). The five types of problem sites, in order of decreasing frequency, were: culverts with fill intact, road gullies, washouts, various diversion problems, and plugged culverts (p. 17).

Culverts with fill intact were the most common problem site (28 percent of total) and were of two types: log culverts and pipe culverts. Each log culvert stored an estimated 23 to 26 cubic yards of sediment, which would be released slowly as the logs rotted. Removal would be difficult due to heavy vegetative cover on the culvert (spruce, alders, mosses) and difficulty of access. The average sediment delivery potential rating was 9; the problem priority rating was 4.7. Pipe culverts stored about 6 to 8 cubic yards of sediment that would be released when the culverts failed. The average sediment delivery potential rating for pipe culverts was 6.1; the problem priority rating was 4.8 (p. 17).

Culverts plugged with debris were the least frequent of the problem sites. At these sites, seasonally active watercourses were being rerouted across the road. The average sediment delivery potential rating was 5.2; the problem priority was 5.2 (p. 17).

Research Results by Best Management Practice

BMP 149—Rule 4.d. Conduct regular preventive maintenance operations to avoid deterioration of the roadway surface.

See Rule 4.d.iii.(c)., maintenance of the road surface (BMP's 166 and 167).

BMP 150—Rule 4.d. Conduct regular preventive maintenance operations to minimize disturbance and damage to forest productivity, water quality, and fish and wildlife habitat.

See subrules below (BMP's 151 through 188) and the General Erosion Research Summary for additional information.

BMP 151—Rule 4.d.i. Sidecast all debris associated with road maintenance in a manner to prevent its entry into streams.

No references were found.

BMP 152—Rule 4.d.i. Sidecast all slide material associated with road maintenance in a manner to prevent its entry into streams.

No references were found.

BMP 153—Rule 4.d.ii. Repair slumps causing stream sedimentation.

Burroughs and King 1989, Horse Creek Study Area, Nez Perce National Forest—Sediment flow transport from rills and gullies on fillslopes was measured for 2 years after road construction. The longest average transport distance, 80.4 feet, was for sediment flows from rills formed in slumped material (pp. 8-9).

See Rule 4.d.ii., slide repair rule (BMP 155) for additional information.

BMP 154—Rule 4.d.ii. Stabilize slumps causing stream sedimentation.

See Rule 4.d.ii., slump repair rule (BMP 153), and the slide repair rule (BMP 155).

BMP 155—Rule 4.d.ii. Repair slides causing stream sedimentation.

Day and Megahan 1977, Clearwater National Forest—The authors directed an inventory of 629 new landslides (including slumps and other mass failures over 10 cubic yards in volume) over a 3-year period (1974-1976). The year 1974 had more landslide activity than average due to a rain-on-snow event in January (p. 1). Total volume of the slides was 716,500 cubic yards; of this, 166,000 cubic yards were delivered to streams (p. 6). The average annual cost of road repair was estimated to be $130,000; the average annual cost of road stabilization was estimated to be $1,100,000 (p. 6).

Megahan and others 1979, Clearwater National Forest and Middle Fork Payette River drainage, Boise National Forest—On the Clearwater National Forest, 629 new landslides (including slumps and other mass failures over 10 cubic yards in volume) were inventoried over a 3-year period (1974-1976). In the Middle Fork Payette River drainage, 789 landslides (mass failures over 10 cubic yards in volume) of varying ages were inventoried. On average, 19 percent of the slide material was delivered to a stream (p. 121); a total of 304,000 cubic meters of material was delivered to streams (p. 135). The costs of road repair and slide stabilization were estimated for the Clearwater slides (p. 135; or see Day and Megahan 1977, summary above). The costs of stabilization were about nine times greater than road repair.

BMP 156—Rule 4.d.ii. Stabilize slides causing stream sedimentation.
See Rule 4.d.ii., slide repair rule (BMP 155).

BMP 157—Rule 4.d.ii. Repair other erosion features causing stream sedimentation.
See Rule 4.d.ii., slide repair rule (BMP 155).

BMP 158—Rule 4.d.ii. Stabilize other erosion features causing stream sedimentation.
See Rule 4.d.ii., slide repair rule (BMP 155).

BMP 159—Rule 4.d.iii.(a). Keep culverts functional (active roads).
No references were found.

BMP 160—Rule 4.d.iii.(a). Keep ditches functional (active roads).

Arnold and Lundeen 1968, South Fork Salmon River drainage—A survey of road erosion on the roads producing the most sediment in the drainage found that 65 percent of sediment originated from fillslopes, 10 percent from cutslopes and ditches, 21 percent from maintenance wasting of cutslope material, and 4 percent from road surfaces (p. 117).

Megahan and others 1983, Silver Creek Study Area, Boise National Forest—Long-term (45-year) cutslope erosion was estimated using exposed tree roots. The authors noted that road maintenance is the primary cause of long-term accelerated cutslope erosion. Removal of slough material at the base of the roadcut during maintenance operations interferes with the natural slope-forming process, removes a favorable site for vegetation growth, and reinitiates slope erosion processes. The authors suggested that removal of the material deposited at the base of the roadcut should be avoided or minimized whenever possible, on forest roads used infrequently, for instance (p. 28).

Burroughs and King 1989, various sites, literature review—Maintenance of the ditch often undercuts the cutslope and initiates cutslope erosion processes (pp. 12-13).

BMP 161—Rule 4.d.iii.(b). During and upon completion of seasonal operations, crown the road surface (active roads) (first alternative).
No references were found.

BMP 162—Rule 4.d.iii.(b). During and upon completion of seasonal operations, outslope the road surface (active roads) (second alternative).

BMP 163—Rule 4.d.iii.(b). During and upon completion of seasonal operations, inslope the road surface (active roads) (third alternative).
See Rule 4.b.iv., outsloping and insloping rules (BMP's 97 and 98).

BMP 164—Rule 4.d.iii.(b). During and upon completion of seasonal operations, water bar the road surface (active roads) (fourth alternative).
See Rule 4.b.iv., dips, water bars, and cross drains (BMP's 100 through 102).

BMP 165—Rule 4.d.iii.(b). During and upon completion of seasonal operations, remove berms from the outside edge except those intentionally constructed for protection of fills (active roads).
See Rule 4.c.vi., berm removal (BMP 134).

BMP 166—Rule 4.d.iii.(c). Maintain the road surface as necessary to minimize erosion of the subgrade (active roads).

Packer and Christensen 1964, 720 sites in Idaho and Montana, representing six soil groups—Previous research had indicated that secondary logging road surfaces deteriorate rapidly when rill depths exceed 1 inch (p. 2). Based on the research later reported in Packer (1967), the authors suggested cross drain spacings to prevent 83 percent of the cases of 1-inch rill formation. A table (pp. 13-15) gives recommended spacings by road grade and soil type, with adjustments for topographic position, aspect, slope steepness, and the percent of cases in which 1-inch rill formation is prevented.

Packer 1967, 720 sites in Idaho and Montana, representing six soil groups—This publication explains the theoretical basis, research design, and data analysis that led to the field guide of Packer and Christensen (1964). Fourteen road and watershed variables were tested as predictors of surface water flow distance producing 1-inch rills. The most important variable was the proportion of soil particles and water-stable aggregates larger than 2 mm on the road surface.

Although this property is related to the soil group, the benefits of larger particles can be derived on all soil types by surfacing roads with gravel or crushed rock (pp. 8-9). The multiple regression equation developed from the most important predictive variables was used to make a table (p. 11), which is the same as the table in Packer and Christensen (1964, pp. 13-15).

Megahan 1974b, four sites in the Idaho Batholith: Deep Creek, Silver Creek, Bogus Basin, and Deadwood River—Data on roadfill erosion or total road prism erosion were used to develop a negative exponential equation showing surface erosion on severely disturbed granitic soils over time. By far the greatest percentage of erosion occurs in the first and second years after construction (p. 12). In the first year, erosion rates are about 1,000 times greater than on undisturbed lands, where rates average 0.07 tons per square mile per day (p. 12). Additional disturbances (such as road grading) result in new cycles of surface erosion (p. 13).

Burroughs and others 1983a, Silver Creek Study Area, Boise National Forest—Simulated rainfall was applied to six road sections representing three different roadway surfaces on a new road. Runoff, sediment, and other variables were measured. Sediment yield was directly correlated with the amount of loose soil on the surface, and inversely correlated with the average size of the loose soil (p. 10). See Burroughs and King (1985) for analysis of the relative effectiveness of dust oil, gravel, and bituminous surfacing.

Burroughs and others 1983b, Rainy Day Road, Nez Perce National Forest—Simulated rainfall was applied repeatedly to new road prism surfaces (cut, tread, and ditch). Initial sediment yields on the unprotected surfaces were high but declined rapidly (p. 9). Sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields also decreased rapidly with successive applications (p. 16). However, the authors noted that the rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22).

The relative effectiveness of rocked road surfaces and ditches was also tested. For ditches, the ratio of sediment yields (p. 14) was:

(Unrocked ditch + untreated cutslope) :
(Rocked ditch + untreated cutslope) = 2.29.

Inclusion of the cutslope sediment in the measurement masked the effectiveness of the rocked ditch (p. 1). A travelway with gravel surfacing produced only 23 percent of the sediment yield of an unsurfaced travelway (p. 1).

Burroughs and King 1985, Silver Creek Study Area, Boise National Forest—This study includes results of the final analysis of the study reported in Burroughs and others (1983a). In that study, simulated rainfall was applied to six road sections representing three different roadway surfaces on a new road. Runoff, sediment, and other variables were measured. Sediment yields from dust oil surfaces were about 13 percent of the yield from the native surfaces at the same gradient; yields from bituminous surfaces were about 1.1 percent of those from native surfaces (p. 187).

Vincent 1985, Silver Creek Study Area, Boise National Forest—Runoff and sedimentation were measured during snowmelt and rainstorms on three sections of native roadway surface varying in gradient from 6.3 to 13.4 percent. The road was constructed in 1980, extensively eroded before the first measurements in 1981, and regraded before the 1982 measurements (pp. 7-9); it was closed to traffic throughout the study period. The road was less erodible in the eroded condition than in the regraded condition; a given amount of runoff generated 75 to 80 percent less sediment for the eroded road in 1981 than for the regraded road in 1982 (p. 39). This is a reversal of the usual time trend, in which lower sediment yields would be expected 2 years after construction.

Megahan 1988, various sites, literature review—For the Interior West, long-term accelerated erosion tends to continue on roads in direct proportion to traffic use and in inverse proportion to the level of road maintenance (p. 341).

Burroughs and King 1989, various sites, literature review—Dust oil surfaces break down under heavy traffic and also contribute volatile chemicals to surface runoff (p. 2). No information was found on sediment reduction by lime or magnesium chloride (p. 2).

Foltz and Burroughs 1990, Tin Cup Creek, Caribou National Forest, east of Idaho Falls—Three 30-minute applications of simulated rainfall were applied to paired roadway surface plots, one rutted and one unrutted. There was a thin layer of loose material over a compacted, bladed road surface (p. 272); gradients of the plots were 8.4 and 9.0 percent (p. 269). Sediment production from the rutted plots decreased sharply over time after the first 20 minutes, reflecting a limited supply of material for transport (p. 272). Sediment production from the unrutted plots rose for about the first 30 minutes, but then maintained a more level sediment production with a slight decline at about 45 minutes.

The sediment levels from the rutted plot were consistently higher than those from the unrutted plot, peaking at 90 grams per second, compared to 32 grams per second for the unrutted plot (p. 272). When the data were adjusted to account for the relative proportions of rutted and unrutted surface on a road with two ruts, the sediment production ratios (two ruts: no ruts) were 2.1 (dry conditions), 1.2 (wet conditions), and 1.0 (very wet conditions) for the three applications of simulated rainfall (pp. 273-274). The authors recommended road closures and similar measures to prevent rutting during wet weather (p. 275).

BMP 167—Rule 4.d.iii.(c). Maintain the road surface as necessary to provide proper drainage (active roads).

Packer and Christensen 1964, 720 sites in Idaho and Montana, representing six soil groups—Previous research had indicated that secondary logging road surfaces deteriorate rapidly when rill depths exceed 1 inch (p. 2). Based on the research later reported in Packer (1967), the authors suggested cross drain spacings to prevent 83 percent of the cases of 1-inch rill formation. A table (pp. 13-15) gives recommended spacings by road grade and soil type, with adjustments for topographic position, aspect, slope steepness, and the percent of cases in which 1-inch rill formation is prevented.

Packer 1967, 720 sites in Idaho and Montana, representing six soil groups—This publication explains the theoretical basis, research design, and data analysis that led to the field guide of Packer and Christensen (1964). Fourteen road and watershed variables were tested as predictors of surface water flow distance producing 1-inch rills. The most important variable was the proportion of soil particles and water-stable aggregates larger than 2 mm on the road surface. Although this property is related to the soil group, the benefits of larger particles can be derived on all soil types by surfacing roads with gravel or crushed rock (pp. 8-9). The multiple regression equation developed from the most important predictive variables was used to make a table (p. 11), which is the same as the table in Packer and Christensen (1964, pp. 13-15).

Arnold and Lundeen 1968, South Fork Salmon River drainage—A survey of road erosion on the roads producing the most sediment in the drainage found that 65 percent of sediment originated from fillslopes, 10 percent from cutslopes and ditches, 21 percent from maintenance wasting of cutslope material, and 4 percent from road surfaces (p. 117).

Hartsog and Gonsior 1973, South Fork Salmon River drainage, Payette National Forest—During the construction period and the early period of use, an engineering research team evaluated a road designed to minimize watershed impacts. The road had been designed as an outsloped road, but did not function as one because of trenches left by skidding tractors and skidded logs, and because of berms left along the road's edge during grading (p. 13). The authors felt that outsloping would seldom function as designed due to concentrations of water caused by wheel depressions and slight differences in soil properties. They recommend outsloping only where surfaces are "relatively nonerodible" such as full-bench sections (p. 20).

They further note that insloping can result in considerable sediment movement unless cutslopes and ditches are stabilized. They suggest that roads should be designed, graded, and surfaced to carry water along the tread, and that provisions should be made to filter or settle out sediment before road runoff reaches streams (p. 21).

Burroughs and others 1983b, Rainy Day Road, Nez Perce National Forest—Simulated rainfall was applied repeatedly to new road prism surfaces (cut, tread, and ditch). Initial sediment yields on the unprotected surfaces were high but declined rapidly (p. 9). Sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields decreased rapidly with successive applications (p. 16). The rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22).

Megahan and others 1983, Silver Creek Study Area, Boise National Forest—Long-term (45-year) cutslope erosion was estimated using exposed tree roots. The authors noted that road maintenance is the primary cause of long-term accelerated cutslope erosion. Removal of slough material at the base of the roadcut during maintenance operations interferes with the natural slope-forming process, removes a favorable site for vegetation growth, and rejuvenates slope erosion processes. The authors suggested that removal of the material deposited at the base of the roadcut should be avoided or minimized whenever possible, on forest roads used infrequently, for instance (p. 28).

Burroughs and King 1989, various sites, literature review—Ditch maintenance often undercuts the cutslope and reinitiates cutslope erosion processes (pp. 12-13).

The authors summarize two studies showing the influence of drainage from the road surface onto the fill (Carlton and others 1982; Tennyson and others 1981). In the Horse Creek Study Area (Nez Perce National Forest), the average transport distances of sediment flows below fillslopes were more than twice as great if they were influenced by travelway drainage (58.8 feet compared to 25.8 feet). These figures are for sediment flows that are not associated with windrows, culverts, or slumps (p. 9), for 2 years after road construction. In the Gospel Hump management areas, transport distances below fills were generally greater for sediment flows influenced by travelway drainage (p. 9).

Foltz and Burroughs 1990, Tin Cup Creek, Caribou National Forest, east of Idaho Falls—Three 30-minute applications of simulated rainfall were applied to paired roadway surface plots, one rutted and one unrutted. There was a thin layer of loose material over a compacted, bladed road surface (p. 272); gradients of the plots were 8.4 and 9.0 percent (p. 269). Sediment production from the rutted plots decreased sharply over time after the first 20 minutes, reflecting a limited supply of material for transport (p. 272). Sediment production from the unrutted plots rose for about the first 30 minutes, but then maintained a more level sediment production with a slight decline at about 45 minutes.

The sediment levels from the rutted plot were consistently higher than those from the unrutted plot, peaking at 90 grams per second, compared to 32 grams per second for the unrutted plot (p. 272). When the data were adjusted to account for the relative proportions of rutted and unrutted surface on a road with two ruts, the sediment production ratios (two ruts: no ruts) were 2.1 (dry conditions), 1.2 (wet conditions), and 1.0 (very wet conditions) for the three applications of simulated rainfall (pp. 273-274). The authors recommended road closures and similar measures to prevent rutting during wet weather (p. 275).

BMP 168—Rule 4.d.iii.(d). If road oil is used, apply it in such a manner as to prevent its entry into streams (active roads).

Megahan 1988, various sites, literature review—The author was unable to find any literature documenting changes in water quality due to chemicals used in road maintenance (p. 338).

Burroughs and King 1989, various sites, literature review—Dust oil surfaces break down under heavy traffic and also contribute volatile chemicals to surface runoff (p. 2).

BMP 169—Rule 4.d.iii.(d). If other surface-stabilizing materials are used, apply them in such a manner as to prevent their entry into streams (active roads).

Megahan 1988, various sites, literature review—The author was unable to find any literature documenting changes in water quality due to chemicals used in road maintenance (p. 338).

Burroughs and King 1989, various sites, literature review—No information was found on sediment reduction by lime or magnesium chloride (p. 2).

BMP 170—Rule 4.d.iv.(a). Following termination of active use, clear ditches (inactive roads).

See Rule 4.d.iii.(a)., functional ditches (active roads) (BMP 160).

BMP 171—Rule 4.d.iv.(a). Following termination of active use, clear culverts (inactive roads).

No references were found.

BMP 172—Rule 4.d.iv.(a). Following termination of active use, crown the road surface (inactive roads) (first alternative).

No references were found.

BMP 173—Rule 4.d.iv.(a). Following termination of active use, outslope the road surface (inactive roads) (second alternative).

BMP 174—Rule 4.d.iv.(a). Following termination of active use, inslope the road surface (inactive roads) (third alternative).

See Rule 4.b.iv., outsloping and insloping rules (BMP's 97 and 98).

BMP 175—Rule 4.d.iv.(a). Following termination of active use, water bar the road surface (inactive roads) (fourth alternative).

See Rule 4.b.iv., dips, water bars, and cross drains (BMP's 100 through 102).

BMP 176—Rule 4.d.iv.(a). Following termination of active use, otherwise leave the road surface in a condition to minimize erosion (inactive roads) (fifth alternative).

No references were found; see Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122), and the General Erosion Research Summary for additional information.

BMP 177—Rule 4.d.iv.(a). Following termination of active use, continue maintenance of drainage structures as needed (inactive roads).

See Rule 4.d.iii.(a)., functional culverts and ditches (active roads) (BMP's 159 and 160).

BMP 178—Rule 4.d.iv.(b). Roads may be permanently blocked to vehicular traffic (inactive roads).

Clifton and Megahan 1988, South Fork Salmon River drainage, Payette and Boise National Forests—Closed roads were inventoried to evaluate surface and mass erosion conditions (p. 1). "Intensive surveys" were conducted on 12.3 miles of road in two watersheds, representing three landtypes (p. 1). Erosion classes were used for surface erosion ratings (1 = natural, 2 = very low, 3 = low, 4 = moderate, and 5 = high) (p. 2). Roads with light use (foot, horse, or motorcycle) showed greater average surface erosion than those with no use (p. 4).

Megahan 1988, various sites, literature review—Surface erosion rates tend to be directly proportional to the level of traffic (p. 341).

See Rule 4.d.iv.(b)., seasonal blockage (inactive roads) (BMP 179).

BMP 179—Rule 4.d.iv.(b). Roads may be seasonally blocked to vehicular traffic (inactive roads).

Burroughs and others 1983b, Rainy Day Road, Nez Perce National Forest—Simulated rainfall was applied repeatedly to new road prism surfaces (cut, tread, and ditch). Initial sediment yields on the unprotected surfaces were high but declined rapidly (p. 9). Sediment yields increased 108 percent when the unsurfaced road tread was rutted rather than unrutted; these yields also decreased rapidly with successive applications (p. 16). The rapid armoring that occurred on these study plots might not have occurred if traffic had been present (p. 22).

Megahan 1988, literature review, various sites—Surface erosion rates tend to be directly proportional to the level of traffic (p. 341).

Foltz and Burroughs 1990, Tin Cup Creek, Caribou National Forest, east of Idaho Falls—Three 30-minute applications of simulated rainfall were applied to paired roadway surface plots, one rutted and one unrutted. There was a thin layer of loose material over a compacted, bladed road surface (p. 272); gradients of the plots were 8.4 and 9.0 percent (p. 269). Sediment production from the rutted plots decreased sharply over time after the first 20 minutes, reflecting a limited supply of material for transport (p. 272). Sediment production from the unrutted plots rose for about the first 30 minutes, but then maintained a more level sediment production with a slight decline at about 45 minutes.

The sediment levels from the rutted plot were consistently higher than those from the unrutted plot, peaking at 90 grams per second, compared to 32 grams per second for the unrutted plot (p. 272). When the data were adjusted to account for the relative proportions of rutted and unrutted surface on a road with two ruts, the sediment production ratios (two ruts: no ruts) were 2.1 (dry conditions), 1.2 (wet conditions), and 1.0 (very wet conditions) for the three applications of simulated rainfall (pp. 273-274). The authors recommended road closures and similar measures to prevent rutting during wet weather (p. 275).

BMP 180—Rule 4.d.v.(a). Leave the road in a condition suitable to control erosion by outsloping (abandoned roads) (first alternative).

See Rule 4.b.iv., outsloping and insloping rules (BMP's 97 and 98).

BMP 181—Rule 4.d.v.(a). Leave the road in a condition suitable to control erosion by water barring (abandoned roads) (second alternative).

See Rule 4.b.iv., dips, water bars, and cross drains (BMP's 100 through 102).

BMP 182—Rule 4.d.v.(a). Leave the road in a condition suitable to control erosion by seeding (abandoned roads) (third alternative).

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—Erosion associated with logging and logging road construction was reduced by use of "good logging practices" including seeding, harrowing, and cross draining of roads following logging in 1953 and 1954 (p. 665). By 1958, the perennial grasses that had been seeded on the roadways were well established and erosion was negligible during the most intense storm (2.82 inches of rain per hour for 10 minutes) of the 7-year study period (p. 668).

Megahan and Kidd 1972a,b, Zena Creek Study Area, Payette National Forest—The authors studied erosion and sedimentation from logging and road construction. Roads built in October 1961 were seeded and water barred after logging was completed in November 1962. The average sedimentation rate in ephemeral drainages below roads for 4.8 years after logging was 51.0 tons per square mile per day. No data were collected for comparison on roads that were not seeded or water barred. Sedimentation rates on nearby undisturbed watersheds averaged 0.07 tons per square mile per day. A return to predisturbance levels of erosion was not expected due to continued roadcut and tread erosion.

Clifton and Megahan 1988, South Fork Salmon River drainage, Payette and Boise National Forests—Closed roads were inventoried to evaluate surface and mass erosion conditions (p. 1). "Intensive surveys" were conducted on 12.3 miles of road in two watersheds, representing three landtypes. "Extensive surveys" were conducted on 63.2 miles of road in four watersheds, representing 14 landtypes (p. 1). The following results are from the intensive survey data.

Erosion classes were used for surface erosion ratings (1 = natural, 2 = very low, 3 = low, 4 = moderate, and 5 = high) (p. 2). Average values for roadfills and road tread were each slightly less than 2, while the average value for roadcuts was 2.6 (p. 3). On all road prism components (roadcut, road tread, and roadfill), correlation analyses showed that as ground cover densities increased, surface erosion decreased. Roadcuts were most sensitive to changes in cover density (p. 5). Ground cover included litter and rocks as well as vegetative cover.

Multiple regression analyses also were conducted for each component of the road prism. Of 19 variables tested, the roadcut cover density and bedrock weathering class explained 86 percent of the variance in roadcut surface erosion (p. 6). Of 40 variables tested, the roadfill cover density explained 69 percent of the variance in roadfill surface erosion (p. 7). Of 25 variables tested, the percent road tread cover outside wheel tracks explained 53 percent of the variance in road tread surface erosion (p. 6).

Because cutslopes exhibited the greatest erosion and were more sensitive to changes in cover, the authors recommended that cutslope revegetation be given priority for rehabilitation measures (p. 6). Average cover densities were much lower on cutslopes (23 percent for head and 38 percent for toe) than on road treads (67 percent) and fills (74 percent) (p. 3).

See Clifton and Thompson (1989) for a followup study.

Clifton and Thompson 1989, South Fork Salmon River drainage, Payette and Boise National Forests—Surface and mass erosion were evaluated on 13 closed logging roads about 20 years after road closure (p. 3). Seven landtypes were represented in the four drainages studied (p. 3).

Erosion classes were used for surface erosion ratings (1 = natural, 2 = very low, 3 = low, 4 = moderate, and 5 = high). Overall, surface erosion rates were in the 1 to 2 range; roadcuts had slightly higher erosion (p. 3). Regression analysis showed that 73 percent of the variation in surface erosion (for cut, tread, and fill combined) was explained by the cover density variable (p. 4). Ground cover included litter and rocks, as well as vegetative cover. Average cover densities were 85 percent on roadcuts, 90 percent on road tread, and 91 percent on roadfills (p. 13).

See Rule 4.c.iii., stabilization of exposed material by seeding (BMP 117), and the General Erosion Research Summary for additional information.

BMP 183—Rule 4.d.v.(a). Leave the road in a condition suitable to control erosion by other suitable methods (abandoned roads) (fourth alternative).

Haupt and Kidd 1965, Boise Basin Experimental Forest, Boise National Forest—Erosion associated with logging and logging road construction was reduced by use of "good logging practices" including seeding, harrowing, and cross draining of roads following logging in 1953 and 1954 (p. 665). By 1958, the perennial grasses that had been seeded on the roadways were well established; erosion was negligible during the most intense storm (2.82 inches of rain per hour for 10 minutes) of the 7-year study period (p. 668).

Megahan and Kidd 1972a,b, Zena Creek Study Area, Payette National Forest—Erosion and sedimentation from logging and road construction was studied. Roads built in October 1961 were seeded and water barred after logging was completed in November 1962. The average sedimentation rate in ephemeral drainages below roads for 4.8 years after logging was 51.0 tons per square mile per day. No data were collected for comparison on roads that were not seeded or water barred. Sedimentation rates on nearby undisturbed watersheds averaged 0.07 tons per square mile per day. A return to predisturbance levels of erosion was not expected due to continued roadcut and tread erosion.

See Rule 4.c.iii., stabilization of exposed material (BMP's 117 through 122) and the General Erosion Research Summary for additional information.

BMP 184—Rule 4.d.v.(b). Clean ditches (abandoned roads).

See Rule 4.d.iii.(a)., functional ditches—active roads (BMP 160).

BMP 185—Rule 4.d.v.(c). Block the road to vehicular traffic (abandoned roads).

See Rule 4.d.iv.(b)., seasonal and permanent road blocks—inactive roads (BMP's 178 and 179).

BMP 186—Rule 4.d.v.(d). Remove bridges if required by the department (abandoned roads).

No references were found.

BMP 187—Rule 4.d.v.(d). Remove culverts if required by the department (abandoned roads) (first alternative).

Jensen and Finn 1966, Zena Creek Study Area, Payette National Forest—In the Deep Creek drainage, road rehabilitation efforts were made on 8.47 miles of road in 1965. Rehabilitation efforts consisted of digging channels across the road to reopen ephemeral drainages, constructing dips every 100 feet, and removing all culverts and fill material in draws (p. 87). The roadway was seeded to perennial grasses (p. 90). The authors recommended using the same techniques in future rehabilitation efforts on decomposed granitic landtypes, using a dragline (if possible without major reconstruction) and a D-7 or D-8 tractor. The authors noted, however, that even with such efforts, it would be impossible to stop most of the accelerated sedimentation or to restore the natural hydrologic function that had been altered by roadcuts (p. 91).

Clifton and Thompson 1989, South Fork Salmon River drainage, Payette and Boise National Forests—Surface and mass erosion were evaluated on 13 closed logging roads about 20 years after road closure (p. 3). Seven landtypes were represented in the four drainages studied (p. 3).

Problem sites with potential for sediment delivery to streams were identified and assigned values for potential delivery to streams (1 = no potential through 9 = supplied directly to watercourse) and priority for treatment (1 = high priority through 9 = low priority). The five types of problem sites, in order of decreasing frequency, were: culverts with fill intact, road gullies, washouts, various diversion problems, and plugged culverts (p. 17).

Culverts with fill intact, the most common problem site (28 percent of total), were of two types: log culverts and pipe culverts. Log culverts each stored an estimated 23 to 26 cubic yards of sediment that would be released slowly over time as the logs rotted. Removal would be difficult due to heavy vegetative cover on the culverts (spruce, alders, mosses) and difficult access. The average sediment delivery potential rating was 9; the problem priority rating was 4.7. Pipe culverts stored about 6 to 8 cubic yards of sediment that would be released when the culverts failed. Average sediment delivery potential rating for pipe culverts was 6.1; the priority rating was 4.8 (p. 17).

Culverts plugged with debris were the least frequent problem sites. At these sites, seasonally active watercourses were being rerouted across the road. The average sediment delivery potential rating was 5.2; the problem priority was 5.2 (p. 17).

BMP 188—Rule 4.d.v.(d). Maintain drainage structures as needed (abandoned roads) (second alternative).

See the summary of Clifton and Thompson (1989) under the previous rule (BMP 187).

General Erosion Research Summary

General Erosion Research Summary

The research studies summarized in this section have implications for one or more of the best management practices, but may not address any particular best management practice directly. Parts of the information presented here, or other information from the same reference, may also appear under specific best management practices. As in previous sections of this report, references are listed chronologically (alphabetically within the same year).

Jensen and Finn 1966, Zena Creek Logging Study Area, Payette National Forest—A hydrologic analysis of the study area (13,334 acres) evaluated watershed conditions and made recommendations (pp. 1, 2). Five landtypes were present; the streamcut, decomposed granitic landtype was most susceptible to erosion and sedimentation problems. Management recommendations, some specific to particular landtypes, are given (pp. 7-9).

Average yearly surface erosion from cut, tread and ditch, and fill were given for four landtypes: strongly glaciated granitic soils, periglacial granitic soils, river terrace lands, and decomposed granitic soils. For strongly glaciated granitic soils and river terrace lands, the values for all road prism components were 0.1 inch of surface erosion per year. For periglacial granitic soils, the roadcut value was 0.2 inch of surface erosion per year and the tread and ditch and fill values were 0.1 inch. For the decomposed granitic soils, the roadcut value was 1.0 inch of surface erosion per year, the tread and ditch value was 0.1 inch, and the fill value was 0.5 inch (p. 70).

Bethlahmy 1967, Zena Creek Logging Study Area, Payette National Forest—Erosion from high-intensity simulated rainfall (12.2 centimeters per hour for 30 minutes) on areas logged with group selection (with slash lopped and scattered) and on unlogged areas was a logarithmic function of runoff (p. 3). A small increase in runoff can cause a large increase in erosion (p. 6). Runoff was directly related to the amount of bare soil, that was much greater on southwest aspects (averaging 41.9 percent bare soil) than on northeast aspects (averaging 2.7 percent bare soil) (p. 4). Significantly greater erosion occurred on southwest aspects. Logged plots had significantly greater erosion than unlogged plots for the southwest aspect, but not for the northeast aspect (p. 5).

Meeuwig 1970, seven sites in the Intermountain area, including two forested sites in Idaho: Basalt Range north of Seven Devils, Nez Perce National Forest; Trinity Mountains, Boise National Forest—Eight independent variables were used in a multiple regression equation to predict erosion resulting from simulated high-intensity rainfall (5 inches per hour for 30 minutes):

Logarithm of ovendry weight of eroded soil and organic matter

Versus

A. Proportion of soil surface protected by vegetation and litter
B. Proportion of soil surface protected by vegetation, litter, and stone
D. Sand content of surface inch of soil
E. Organic matter of surface inch of soil
F. Organic matter of surface 2 inches of soil
G. Slope gradient
H. Bulk density of surface 4 inches of soil
L. Air-dry weight of litter.

Of the eight independent variables, protection of the soil surface from direct raindrop impact (A or B) was the most important variable in reducing erosion (p. 5). Gradient was also important, especially on sandy soils (p. 5). Organic matter increased the erodibility of sandy soils, including those on the two Idaho sites (p. 6).

Various equations, graphs, tables, and nomographs show relationships among the variables and predict sheet erosion rates from storms similar to the experimental storm.

See Meeuwig (1971) for a followup report.

Farmer and Van Haveren 1971, laboratory study using soils from three Intermountain sites, including high- and low-elevation sites in the Boise National Forest—A laboratory experiment evaluated the erodibility of bare Intermountain area soils subjected to simulated rainfall. Three slope gradients were tested (2.5, 18, and 32 percent); two rainfall intensities (about 3 or 7 inches per hour) were applied for 30 minutes to saturated soils (p. 2). Erosion by overland flow and by soil splash were evaluated separately.

A graph displayed the interactions among intensity, gradient, and particle size in determining erosion by overland flow (p. 4). Erosion was minimal if either steepness or intensity was low, but increased more than five times when both steepness and intensity were at their maximum values (p. 5). Larger particle sizes had lower erosion rates (p. 5). The soil variables tested were much less important than slope gradient or rainfall intensity (p. 5). Slope gradient and rainfall intensity accounted for 90 percent of the variance in the data; particle size accounted for just 6 percent (p. 5).

For splash erosion, gradient and intensity accounted for 82 percent of the variance, while bulk density and the proportion of sand-size material accounted for 15 percent (p. 7). Interactions were shown in figures (p. 7). Splash erosion increased as bulk density increased; most forest and rangeland soils have a seasonal increase in bulk density from spring to fall (p. 13).

The high-elevation granitic soil was the least erodible of the three soils tested. The other two soils were similar in their erodibility (p. 11). In all cases, bare soils demonstrated little resistance to erosion. Severe erosion during high-intensity rains can be expected on areas with little vegetative cover (p. 13).

Gonsior and Gardner 1971, Zena Creek drainage, Payette National Forest—The authors investigated mass failures to determine their causes and to recommend measures to prevent future failures. Field and laboratory measurements and a slope stability analysis were done. Contributing factors included: natural instability of the area, logging and road construction activities, steepness of roadcut and fillslopes, poor road drainage, lack of fill compaction, inclusion of logs and stumps in fill material, and removal of trees near roads (pp. 30-32). Recommendations for future road construction methods are given (p. 33). Most of these are discussed under the corresponding best management practices.

Meeuwig 1971, seven sites in the Intermountain area, including two forested sites in Idaho—This publication used the same data as Meeuwig (1970), but data from all sites were combined for this analysis rather than analyzed separately. A regression analysis was performed for the combined data set from the seven sites:

Common logarithm of the weight of material eroded during 30 minutes of simulated high-intensity rain

Versus

Percent surface cover (plants and litter)
Litter weight
Slope gradient
Percent clay in surface inch of soil
Percent sand in surface inch of soil
Percent organic matter in surface inch of soil.

As in the 1970 study, surface cover was the most important predictor variable. Cover had a larger effect as slope steepness increased, and slope had a larger effect as cover values decreased. When cover was less than 50 percent, erosion rates doubled for each 10 percent increase in slope (p. 6). Erosion as a function of cover and slope was graphed (p. 6).

Interactions (with respect to relative erodibility) between contents of sand, clay, and organic matter were shown (p. 8). The most erodible soils had high clay, low sand, and low organic matter (p. 9). Three combinations exhibiting low erodibility were (p. 9):

(1) high clay, low sand, and high organic matter;
(2) low clay, high sand, and low organic matter;
(3) low clay, low sand, and any organic matter content.

Burroughs and others 1972, near Lolo Pass at the Idaho-Montana border—In the zone of deepest snowpacks, substantial volumes of water were intercepted during snowmelt (p. 11) at roadcuts averaging 36 inches high (p. 3). Subsurface seepage averaged 58 percent of the total water intercepted during snowmelt; the remainder occurred as overland flow (p. 10). In the central Idaho Batholith, such overland flow from snowmelt is seldom observed (p. 12). See Megahan (1972) for a similar study in the Idaho Batholith. The factors identified as conducive to overland flow during snowmelt were (p. 11):

- A deep snowpack
- Snowmelt delayed until June due to elevation and aspect, then rapid snowmelt
- Moderate slope gradients
- A completely saturated soil mantle or a high water table.

The study indicated that 1 mile of road in the deep snowpack zone would intercept 310 acre-feet of overland flow and subsurface seepage during the spring snowmelt period. Providing drainage for the intercepted water is critical, especially in areas to be logged with jammers, because densities of jammer roads often exceed 10 linear miles per square mile (p. 11). Special measures are also necessary for the prevention of cut and fill erosion (p. 11).

Clayton and Arnold 1972, Idaho Batholith—A classification system for Batholith rocks was presented (pp. 7-8). Management implications of the stability properties of each weathering class are given (pp. 16-17).

Megahan 1972, Pine Creek Study Area, Boise National Forest—Subsurface flow interception was measured along roadcuts deep enough to expose bedrock (average soil depth was about 31 inches) in first order watersheds (p. 351). Subsurface flow was intercepted only during the spring snowmelt period; overland flow was never observed (p. 353). The volume of flow intercepted was about 7.3 times greater than the estimated snowmelt runoff from the road area alone (p. 355). About 35 percent of the total subsurface flow was intercepted by the roadcut (p. 355). Subsurface flow interception was greater in drainage bottoms, but was not limited to those areas (p. 353). The author notes that this large volume of runoff must be considered in road drainage design, drainage structures, and erosion control measures, as well as the potential effects on channels and vegetation (p. 356).

See Burroughs, Marsden, and Haupt (1972) for a related study.

Megahan and Kidd 1972a, b, Zena Creek Study Area, Payette National Forest—Erosion and sedimentation from logging and road construction were studied.

Roads built in October 1961 were seeded and water barred after logging was completed in November 1962. Sediment was measured in ephemeral drainages below roads. The average road sedimentation rate for 1.35 years before logging was 56.2 tons per square mile per day. The average road sedimentation rate for 4.8 years after logging was 51.0 tons per square mile per day. These rates include sediment from both surface and mass erosion. Sedimentation rates on nearby undisturbed watersheds averaged 0.07 tons per square mile per day. Roads increased sedimentation 770 times over the natural rate; of this, 30 percent was from surface erosion and 70 percent was from mass erosion. Jammer and skyline logging increased sedimentation 0.6 times.

Time trends for sediment from surface erosion on logging roads were discussed and shown in tabular and graphical form (Megahan and Kidd 1972a, pp. 8-9). In the first measurement period (November 1961 to June 1962), rates of sedimentation due to surface erosion were 109 tons per square mile per day, 1,560 times the undisturbed rate. The rates decreased rapidly in subsequent measurement periods, then fluctuated from 0 to 100 times the natural rate. High initial sedimentation rates were largely due to fillslope erosion; but these high rates could be avoided by fill stabilization. Continued accelerated road erosion rates were expected due to erosion of weathered granitic bedrock on the road tread and steep road cutslopes.

Mass erosion does not follow time trends in the same manner as surface erosion. It depends more on climatic events and the consideration given to road location, design, construction, and maintenance.

Megahan 1974b, four sites in the Idaho Batholith: Deep Creek, Silver Creek, Bogus Basin, Deadwood River—Data on roadfill erosion or total road prism erosion were used to develop a negative exponential equation describing surface erosion on severely disturbed granitic soils over time. By far the greatest percentage of erosion occurs in the first and second years after construction (p. 12). In the first year, erosion rates are about 1,000 times greater than on undisturbed lands, where rates average just 0.07 tons per square mile per day (p. 12). After 40 years, erosion rates are about 10 times greater than on undisturbed lands (p. 12). Additional disturbances result in new cycles of surface erosion (p. 13).

Erosion control measures are most effective if applied immediately after disturbance (p. 12). Seeding was not recommended because of the erosion that occurs before the seeded vegetation becomes established; mulching or transplants were recommended for immediate erosion control (p. 12).

Burroughs and Thomas 1977, South Fork Payette River near Lowman, Boise National Forest— Rocky Mountain Douglas-fir root numbers and tensile strength over time were measured on clearcut and undisturbed slopes. All sampling areas were within old-growth sites (100 to 200-year-old trees). Tensile strength of tree roots was shown to be an important factor increasing slope stability on logged and unlogged slopes. However, root strength decreases rapidly in the first year after tree felling, and then decreases gradually over time (p. 16).

Day and Megahan 1977, Clearwater National Forest—Based on a survey of 629 landslides, this report gives seven criteria for identifying unstable slopes:

- Steep slopes (generally >60 percent)
- Highly weathered and fractured bedrock; bedrock with high mica or clay content (generally border zone rocks)
- Areas that show a concentration of subsurface water
- Adverse structure (planes of bedrock weakness dip with the slope of the land)
- Impermeable zones within the mantle or bedrock
- A history of landslides (p. 12).

Megahan 1978, Deadwood River Road, Boise National Forest—Fillslope plot studies were used to evaluate surface erosion processes on bare plots and unmulched plots planted with ponderosa pine seedlings (p. 351). The roadfill was 11 years old when the plots were installed, had a southwest aspect, and a gradient of 70 to 75 percent (p. 350).

Three water years (October 1 through September 30) of data were available to test seasonal differences (p. 351). Mean daily erosion was significantly greater during the summer-fall period than during the portions of the winter-spring period without surface snow cover (pp. 351-352). About 80 percent of the total erosion occurred during the summer-fall period (p. 356).

Planted trees significantly reduced (45 percent, significant at the 0.05 level) erosion during the summer-fall periods, but not during the winter-spring periods (20 percent, not significant) (p. 352). During the summer-fall periods, plots with planted trees had significantly less (0.01 level) erosion than the control plots for periods with and without rain (p. 353). Tree planting reduced estimated dry creep erosion (relative to the control) from 1.9 to 1.2 metric tons per square kilometer per day during rainy periods, and from 2.6 to 1.4 metric tons per square kilometer per day during rainfree periods (p. 355).

Dry creep accounted for 15 to 52 percent of the total summer-fall erosion. Wind was an important cause of dry creep, and also increased erosion during rainstorms by about 10 times (p. 357). The erodibility index explained only 25 percent of the variation in erosion (p. 354).

Megahan and others 1979, Clearwater National Forest and Middle Fork Payette River drainage, Boise National Forest—The authors directed an inventory of 1,418 landslides of 8 cubic meters or more (pp. 120, 121) in the two study areas. The data only give frequencies of occurrence; they do not define cause and effect (p. 137).

The average slide volume was 460 cubic meters; on average, about 19 percent or 87 cubic meters was delivered to streams (p. 121). The Clearwater National Forest had an average of 210 new slides per year during the 3-year study; however, 1 year of the three probably had greater than average slide frequency due to climatic events (p. 210). Climatic conditions had effects on both slide frequency and slide characteristics (pp. 128-129). Seventy-two percent of slides were debris slides or debris avalanches; 19 percent were slumps; 7 percent were debris flows or debris torrents; 2 percent were rockfalls (p. 122).

On the Clearwater National Forest, the Border Zone bedrock types had the highest frequency of slides per unit area; Batholith types had the lowest (p. 122). Rock types with a high mica content were the most prone to landslides. Occurrence of bedding planes parallel to sideslopes also increased slide hazard (p. 122). Effects of rock weathering on landslide frequency were not clear (p. 123). In the Belt Series, slide frequency increased with increased fracturing; on the other lithologies (bedrock types) the relationship was not as clear (p. 123).

Forty-seven percent of slides occurred on slopes with gradients between 51 and 70 percent; 28 percent of slides occurred on slopes with gradients between 71 and 90 percent (p. 125). Slide occurrence increased from the ridges downslope to the lower third of the slope (p. 126). The median drainage area above the slides was 0.6 hectares; 90 percent of slides had drainage areas of 4 hectares or less (pp. 126-127). Slide frequency by landtype was given for the Clearwater data (p. 128).

Road construction was the most important factor contributing to landslides. Fifty-eight percent of the slides were associated with roaded areas uninfluenced by logging or fire; another 30 percent were associated with roads in combination with logging or fire. Seven percent of slides were associated with fire only; 2 percent with logging only; 3 percent occurred on undisturbed sites (p. 130).

Sixty-six percent of the road-associated slides originated on roadcuts, 27 percent on roadfills without culverts, and 7 percent on fills with culverts. Forty-seven percent of the volume of road-associated slides originated on roadcuts, 31 percent on fills without culverts, and 21 percent on fills with culverts. However, of the slide material delivered to streams, 33 percent originated on cuts, 51 percent on fills without culverts, and 16 percent on fills with culverts (p. 131).

For roads built to lower standards, landslide frequency decreased. This was attributed to the reduction in excavation required for successively lower standards. The average number of slides per kilometer of road was 2.2 for arterial, 1.2 for collector, 0.6 for service, and 0.2 for temporary or terminal roads (p. 131).

The frequency of landslides tended to increase as either tree or shrub crown cover decreased (p. 132). When crown covers were less than 80 percent, landslide occurrence appeared to be more sensitive to reductions in shrub crown cover than to reductions in tree crown cover. The authors recommended using timber harvest procedures that minimize the disturbance of understory vegetation (p. 132). Landslides were most common 4 to 10 years after logging; landslide frequencies remained elevated for 20 years after logging (p. 133). These time trends were attributed to the loss of root strength through decay (increasing landslides) interacting with growth of new roots (decreasing landslides) (p. 132).

Some of the damages and costs associated with the landslides were given (p. 135). These include the area of slide scars, repair costs, stabilization costs, and volumes of material delivered to streams.

Gray and Megahan 1981, Pine Creek Study Area, Middle Fork of the Payette River drainage, Boise National Forest—Several analyses evaluated the contributions of forest vegetation to slope stability. Vegetation contributes to slope stability through root reinforcement, surcharging (vertical downward force exerted by the weight of the trees), soil arching (when soil begins to move through and around a row of trees firmly embedded or anchored in an unyielding layer), and regulating soil moisture (abstract and p. 2). The analyses showed that many sites in the Idaho Batholith are in a state of marginal equilibrium, and may fail when roads are constructed or trees are harvested (p. 20).

Based on their research, the authors offered management guidelines:

- Limit the size of clearcuts
- Stagger clearcuts in space and time
- Leave buffer zones above and below haul roads, along streams, and in critical areas
- Leave as much residual vegetation as possible
- Favor selection cutting over clearcutting
- Drain surface runoff from roads onto areas of undisturbed vegetation (p. 21).

Tennyson and others 1981, Horse Creek Study Area, Nez Perce National Forest—The authors studied the effects of various road construction and road stabilization methods on erosion, sedimentation, and streamflow. (Only general erosion processes, time trends, and seasonal trends are summarized here. Other results appear elsewhere in this report.) Road construction in the study area began in 1978 and was completed in 1979 (p. 2). Data collected through 1980 were included in the report.

Fillslope erosion included surface and mass erosion. Surface erosion was primarily sheet and rill erosion begun by rainstorms; this process was most active during the first few summer months following construction (p. 11). Mass erosion was primarily slumping of saturated soils during spring snowmelt. Fill erosion was greater in the summer than in the winter, decreasing from the first to the third summer (p. 14). About 44 percent of the rill erosion in fills occurred during intense summer storms in the first 6 to 8 weeks after construction before the slopes had been seeded and hydromulched (pp. 37-38).

Surface and mass erosion processes were also operating on the cutslopes. On the cutslopes, dry ravel (movement not caused by water) was an important surface erosion mechanism (p. 20). No reduction in cutslope erosion over time was apparent; winter erosion was greater than summer erosion (p. 21). Slumping during snowmelt was the major erosive process on cutslopes (p. 67). Cumulative erosion from cutslopes was greater than that from fillslopes during the study (pp. 23, 25).

Various tables and graphs show time trends in the distance sediment flowed below fillslopes (pp. 42, 45-46). Ditch elevation data (measured for 1 year following construction) were variable. There was a general trend toward degradation during snowmelt and aggradation during the summer (p. 70).

Carlton and others 1982, Gospel Hump management areas, Nez Perce National Forest—Erosion plots were established on undisturbed sites, logged sites, and road fillslopes. Most of the harvested sites had been tractor logged; a few had been logged using skyline systems. Fillslopes had been fertilized, seeded, and hydromulched (p. 13). Roads were constructed and the areas were logged in 1978 and 1979; plots were installed in the late summer of 1979 and data were collected from the spring of 1980 through the fall of 1981.

Erosion was not significantly different on the undisturbed and harvested plots. The "percent bare ground" variable alone adequately predicted erosion (pp. 18, 23-24). Equations were developed to predict the time required for recovery following disturbance on undisturbed or logged sites (pp. 25-26, 28).

Rill and gully erosion processes were dominant on the road fillslopes (p. 45). Rill survey data showed that most of the erosion occurred by the first measurement in the spring of 1980 (p. 30). The authors present the results of fillslope regression analyses giving seasonal or yearly erosion over time based on fillslope length and vertical height of the fill (pp. 32-35).

Clayton 1983, Silver Creek Study Area, Boise National Forest—Seismic and resistivity geophysical surveys were used together with vegetation surveys to predict subsurface bedrock properties related to slope stability before road construction (pp. 1, 2). Granitic rock in weathering class 7 (Clayton and Arnold 1972) and highly weathered basic dike rock were grouped together in a category called highly weathered rock; this category represents the greatest hazard for mass failures (pp. 1, 2).

Using the above combination of techniques to predict zones of highly weathered rock produced only one false negative (11 of 12 zones with highly weathered rock were predicted correctly); however, the techniques produced 10 false positives (10 zones predicted to be highly weathered rock were not). Field reviews of the geophysical data are necessary to eliminate false positives. The geophysical surveys were useful in planning the road drainage system (p. 5).

Megahan 1983, Pine Creek Study Area, Boise National Forest—A paired watershed study evaluated the effects of clearcutting and wildfire on the hydrology of small first-order watersheds. Calibration measurements began in 1970. In November 1972 one watershed was clearcut; in August 1973 both watersheds were burned by wildfire (pp. 812-813).

On the clearcut watershed, there were large changes in several hydrologic variables (pp. 811, 816). The volume of subsurface flow intercepted at a roadcut increased 96 percent, with 27 percent higher peak flow rates. Similar changes were not detected on the unlogged watershed. Increased surface and mass erosion hazards are associated with the types and directions of the hydrologic changes observed (p. 811).

The author recommended limiting clearcut size or using other silvicultural systems in areas where mass erosion hazards are a concern (p. 818). He also noted that interception of subsurface flow should be considered in planning road drainage systems and road locations relative to clearcuts (p. 818).

Vincent 1985, Silver Creek Study Area, Boise National Forest—Runoff and sedimentation were measured during snowmelt and rainstorms on three sections of native roadway surface varying in gradient from 6.3 to 13.4 percent. The road was constructed in 1980, extensively eroded before the first measurements in 1981, and regraded before the 1982 measurements (pp. 7-9); it was closed to traffic throughout the study period.

Although 55 percent of the annual precipitation falls as snow (p. 16), and about 91 percent of the snowmelt runs off (p. 28), less than 10 percent of the total annual sediment yield from the road tread occurs during snowmelt (p. 52). However, snowmelt runoff may generate surface or mass erosion of fills if it is discharged onto the fill (p. 28). Road tread sediment production was dominated by short duration moderate- to high-intensity rain (p. 30).

The road was less erodible in the eroded condition than in the regraded condition; a given amount of runoff generated 75 to 80 percent less sediment for the eroded road in 1981 than for the regraded road in 1982 (p. 39).

Sediment yields from the road tread increased with increasing gradient (p. 53). For the graded surface, plots with gradients of 6.3 percent had sediment yields of 21 tonnes per hectare, those with gradients of 9.0 percent had sediment yields of 37 tonnes per hectare and those with gradients of 13.4 percent had sediment yields of 71 tonnes per hectare (p. 57). Gradient effects were more pronounced for snowmelt sediment. (p. 55-56).

Clifton and Megahan 1988, South Fork Salmon River drainage, Payette and Boise National Forests—Closed roads were inventoried to evaluate surface and mass erosion (p. 1). Surface erosion results are discussed elsewhere in this report; only mass erosion will be discussed here.

Of 168 road segments inventoried, 135 had no mass erosion; 91 percent of the volume of mass erosion was in 14 road segments (p. 7). No statistically significant relationships were found between mass erosion and road gradient, hill slope gradient, road tread erosion class, cut erosion class, fill erosion class, road runoff index, road runoff source, occurrence of culverts, aspect, or overall surface erosion index (p. 8). Certain landtypes were more prone to landslides than others (p. 24).

See Clifton and Thompson (1989) for a followup report.

Clifton and Thompson 1989, South Fork Salmon River drainage, Payette and Boise National Forests—Surface and mass erosion conditions were evaluated on 13 closed logging roads about 20 years after road closure (p. 3). Seven landtypes were represented in the four drainages studied (p. 3).

Surface erosion was assessed as a class variable. In general, surface erosion was rated natural to very low (p. 3). Surface erosion was greatest on landtype 111a, especially on the cutslopes in that landtype; the lowest values were in landtype 102. However, the range in average surface erosion rating by landtype was quite limited.

Mass erosion was the dominant erosion process in the study area (p. 11). Long-term mass erosion rates were about 36 cubic yards per mile of road per year, or 3.4 cubic yards per acre of road area per year, about 85 times greater than the erosion rate on undisturbed sites in the area (p. 8). Slope gradient explained 97 percent of the variance in landslide volume. Most landslides occurred on 40 to 90 percent slopes. The highest frequency of landslides per mile of road was on landtype 120e-1 (p. 9).

Ketcheson and Megahan 1990, Silver Creek Study Area, Boise National Forest—Volumes and lengths of sediment flows below roads were measured for 4 years after road construction. Only 14 of the 346 sediment flows observed originated after the first year. Sixty-nine percent of sediment movement occurred in the first year; 27 percent of that occurred during construction. By the fourth year, 254 of 346 sediment flows showed no change in length, width, or volume (p. 11).

Megahan and others 1991, Silver Creek Study Area, Boise National Forest—Sediment from bordered fillslope erosion plots was measured for 3 years after road construction (p. 54). Several variables were tested as predictors of fillslope erosion, including elevation, slope gradient, azimuth, direct beam solar radiation, ground cover density, and erosivity index. The only statistically significant variables were ground cover density and snow-free period rainfall erosivity (p. 55-56). These were used to develop a prediction equation (p. 56). A graph (p. 56) was developed to show the probability of occurrence of sediment yields from granitic roadfills as a function of ground cover density. Methods to adjust the predicted values for other slope lengths and gradients were given (p. 57).

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A search was conducted for quantitative Idaho research results on the effectiveness of the Idaho Forest Practices Act rules and regulations pertaining to timber harvest and forest road construction and maintenance. These rules and regulations are designated as the "best management practices" for the prevention of nonpoint source pollution from silviculture under the provisions of the Federal Clean Water Act. For each practice, the relevant research results are summarized; more general summaries for related groups of practices are also provided.

Keywords: erosion control, nonpoint pollution, logging, road construction, road maintenance, water pollution

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