3C: Road Construction/Reconstruction

Management Measure for Road Construction/Reconstruction

(1) Follow preharvest planning (as described under the Management Measure for Preharvest Planning) when constructing or reconstructing the roadway.

(2) Follow designs planned under the Management Measure for Preharvest Planning for road surfacing and shaping.

(3) Install road drainage structures according to designs planned under the Management Measure for Preharvest Planning and regional storm return period and installation specifications. Match these drainage structures with terrain features and with road surface and prism designs.

(4) Guard against the production of sediment when installing stream crossings.

(5) Protect surface waters from slash and debris material from roadway clearing.

(6) Use straw bales, silt fences, mulching, or other favorable practices on disturbed soils on unstable cuts, fills, etc.

(7) Avoid constructing new roads in streamside management areas to the extent practicable.

Management Measure Description

Road construction is one of the largest potential sources of forest activity-produced sediment (Megahan, 1980), and road and drainage crossing construction practices that minimize sediment delivery to surface waters are essential for protecting water quality. Water quality degradation resulting from forest roads is mostly attributable to sediment loss during road construction, erosion that occurs within a few years after road construction, soil loss from heavy road use, and road failure during storm events that exceed the road's design capacity. An early study of erosion from road construction concluded that the amount of sediment produced by road construction is directly related to the percent of area occupied by roads, whether a road is given a protective surface, and the amount of protection provided to loose soils on back slopes and fill slopes (King, 1984) (Table 3-11). Best management practices related to these aspects of road construction, and for stream crossing construction, are the subject of this management measure. Erosion and water quality degradation are also problems associated with older, unmaintained roads, and BMPs for road maintenance are the subject of the next management measure.

General Road Construction Considerations

Road design and construction that are tailored to the topography and soils and that take into consideration the overall drainage pattern in the watershed where the road is being constructed can prevent road-related water quality problems. Lack of adequate consideration of watershed and site characteristics, road system design, and construction techniques appropriate to site circumstances can result in mass soil movements, extensive surface erosion, and severe sedimentation in nearby water bodies. The effect that a forest

Table 3-11. Effects of Several Road Construction Treatments on Sediment Yield in Idaho (King, 1984)

Watershed Area (acres)	Area in Roads (percent)	Treatment	Increase of Annual Sediment Yield[a] (percent)
207	3.9	Unsurfaced roads; Untreated cut slope; Untreated fill slope	156
161	2.6	Unsurfaced roads; Untreated cut slope dry seeded	130
364	3.7	Surfaced roads; Cut and fill slopes straw mulched and seeded	93
154	1.8	Surfaced roads; Filter windrowed; Cut and fill slopes straw mulched and seeded	53
70	3.0	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	25
213	4.3	Surfaced roads; Filter windrowed; Cut and fill slopes hydro-mulched and seeded	19

[a] Measured in debris basins.

road network has on stream networks largely depends on the extent to which the road and stream networks are interconnected. Road networks can be hydrologically connected to stream networks where road surface runoff is delivered directly to stream channels at stream crossings or via ditches or gullies that direct flow off of the road and then to a stream, and where road cuts transform subsurface flow into surface flow in road ditches or on road surfaces that delivers sediment and water to streams much more quickly than without a road present and increases the risk of mass wasting (Jones and Grant, 1996; Montgomery, 1994; Wemple et al., 1996). The combined effects of these drainage network connections are increased sedimentation and peak flows that are higher and arrive more quickly after storms. This in turn can lead to increased instream erosion and stream channel changes. This effect is strongest in small watersheds (Jones et al., In press).

Site characteristics are first considered during preharvest planning, and it is important to review the harvesting plan at the harvest site before construction begins to verify assumptions made during planning. On-site verification of information from topographic maps, soil maps, and aerial photos is necessary to ensure that locations where roads are to be cut into slopes or built on steep slopes or where skid trails, landings, and equipment maintenance areas are to be located are appropriate to the use. If an on-site visit indicates that changes to road, skid trail, or landing locations can reduce the risk of erosion, the project manager can make these changes prior to construction, and in some cases as the project progresses.

Road drainage features tailored to the site and its conditions prevent water from pooling or collecting on road surfaces and thereby prevent saturation of the road surface, which can lead to rutting, road slumping, and channel washout. It is especially important to ensure that road drainage structures are well constructed and designed for use during logging operations because the heavy vehicle use during harvesting creates a high potential for the contribution of large quantities of sediment to runoff.

Some roads are temporary or seasonal use roads, and their construction should not generally involve the high level of disturbance generated by the construction of permanent, high-standard roads. However, temporary or low-standard roads still need to be constructed and maintained to prevent erosion and sedimentation, and many of the BMPs discussed for this management measure are applicable to temporary road construction.

In a study in three headwater watersheds in the mountains of central Idaho, 70 percent of sediment deposition from roads constructed on the watersheds, where the slope ranged from 15 to 40 percent, occurred during the first year after construction, and one-fourth of this deposition occurred during road construction (Ketcheson and Megahan, 1996). In this study, sediment usually traveled less than 100 meters (m) from its source. The distance that sediment traveled varied depending on its source: the distance traveled from fills, rock drains, berm drains, and landings was between 4 m and 20 m, while that from cross drains was 50 m. The maximum travel distance from some cross drains was more than 250 m. Cross drains have a larger source area from which runoff is collected, including the road prism and upslope watershed area, and this accounted for more sediment being deposited than from all other sources combined. These findings highlight the importance of road placement, design, and construction in relation to watercourse location and the installation of BMPs to control runoff sedimentation from roads.

Based on the findings of studies such as this, it is clear that erosion control practices need to be applied while a road is being constructed, when soils are most susceptible to erosion, to minimize soil loss to water bodies. Since sedimentation from roads often does not occur incrementally and continuously, but in pulses during large rainstorms, it is important that road, drainage structure, and stream crossing design take into consideration a sufficiently large design storm that has a good chance of occurring during the life of the project. Such a storm might be the 10-year, 25-year, 50-year, or even 100-year, 12- to 24-hour return period storm. Sedimentation cannot be completely prevented during or after road construction, but the process is certainly exacerbated if the road construction and design are inappropriate for the site conditions or if the road drainage or stream crossing structures are insufficient.

Several common practices minimize erosion during road construction. In general, it is recommended that forest roads be constructed as a single lane for minimum width and outsloped with minimal cut-and-fill, where conditions are suitable (Weaver and Hagans, 1984). These roads should cause the least disturbance and have lower maintenance costs. Figure 3-6 illustrates various erosion and sediment control practices. Aspects of road construction addressed by the BMPs discussed under this management measure are introduced below. Further information is provided in the discussions of the individual BMPs.

Road Surface Shape and Composition

The shape of a road is an important component of runoff control. Terminology related to road construction and road shape is illustrated in Figure 3-7. Road drainage and runoff control are obtained by shaping the road surface to be insloping, outsloping, or crowned (Figure 3-8). Road surfaces need to have and maintain one of these shapes at all points to ensure good drainage (Moll et al., 1997). Insloping roads can be particularly effective where soils are highly erodible and directing runoff directly to the fill slope would be detrimental. Outsloped roads tend to dissipate runoff more than insloped roads, which concentrate runoff at cross drain locations, and are useful where erosion of the backfill or

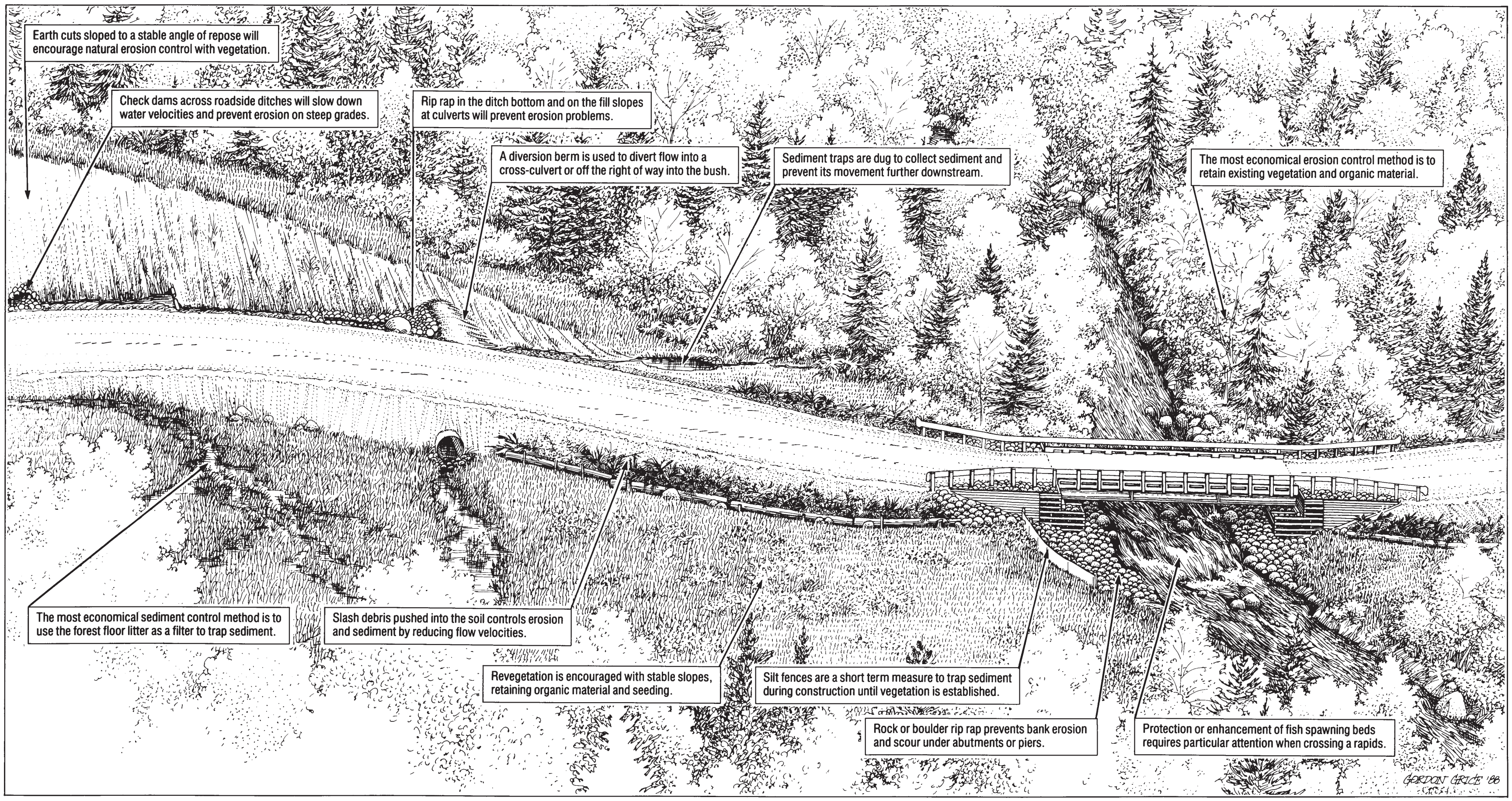

Figure 3-6. Mitigation techniques used for controlling erosion and sediment to protect water quality and fish habitat (Ontario MNR, 1988).

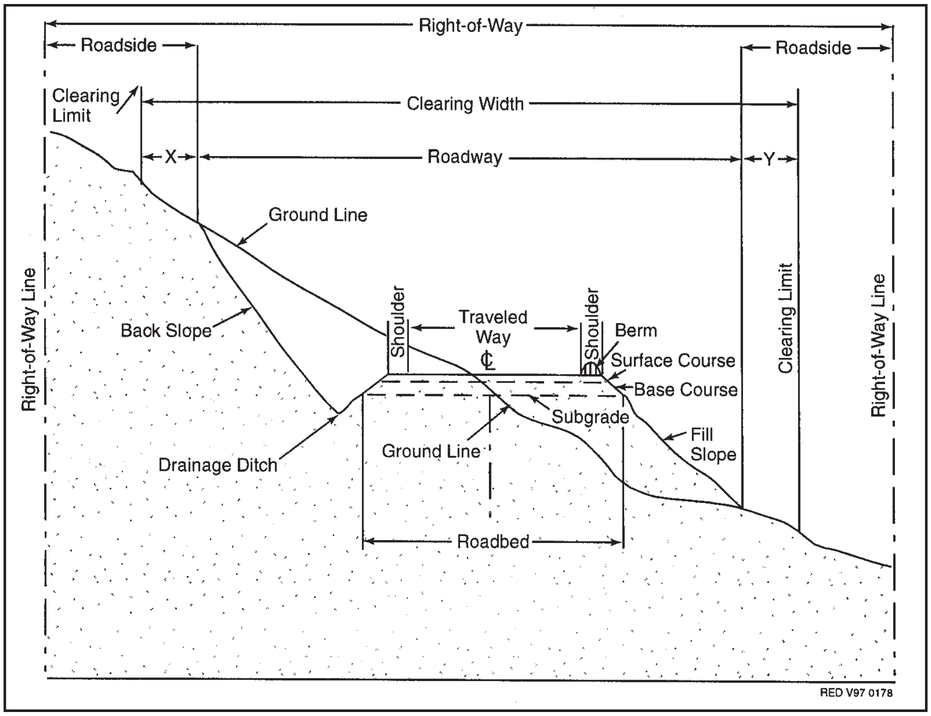

Figure 3-7. Illustration of road structure terms (Moll et al., 1987).

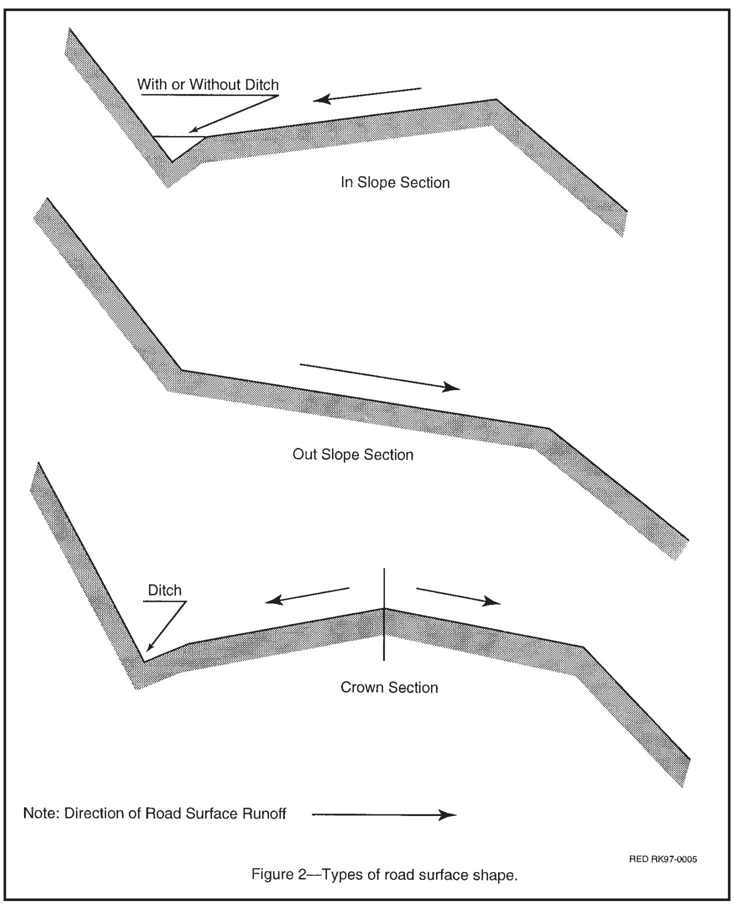

Figure 3-8. Types of road surface shape (Moll et al., 1997).

Sediment Runoff Distance and Quantity Vary with Source

Seventy percent of sediment deposition from roads constructed on three headwater watersheds in the mountains of central Idaho, where the slope ranged from 15 to 40 percent, occurred during the first year after construction, and on-fourth of this occurred during road construction.

Sediment generally traveled less than 100 m from its source. Average sediment travel distances from fills, rock drains, berm drains, and landings were between 4 m and 20 m, while that from cross drains was 50 m. The maximum travel distance from some cross drains was more than 250 m.

The larger source area for runoff from cross drains, including he road prism and upslope watershed areas, accounts for more sediment deposited form them and for the sediment from them traveling farther than from other sources.

(Source: Ketcheson and Megahan, 1996)

ditch soil might be a problem. Crowned roads are particularly suited to two-lane roads and to steep single-lane roads that have frequent cross drains or ditches and ditch relief culverts (Moll et al., 1997). Crowns, inslopes, and outslopes will quickly lose effectiveness if not maintained frequently, due to micro-ruts created by traffic when the road surface is damp or wet.

The composition of a road surface can be chosen to effectively control erosion from the road surface and slopes. It is important to choose a road surface that is suitable to the topography, slope, aspect, soils, and intended use. Small, temporary, dry season roads can be left unsurfaced and decommissioned after use to minimize their impact to water quality. Roads that will be used more intensively or for long periods can have road surfaces formed from native material, aggregates, asphalt, or other suitable materials. Any of these surface compositions can be shaped in one of the ways discussed above. Surface protection of the roadbed and cut-and-fill slopes with a suitable material can

- Minimize soil losses during storms
- Reduce frost heave erosion production
- Restrain downslope movement of soil slumps
- Minimize erosion from softened roadbeds

Numerous studies have been conducted and have demonstrated the potential of a suitable road surface composition to control erosion and sedimentation from forest roads. Swift (1985) found that applying 20 centimeters (cm) of crushed rock to forest roads in the southern Appalachian mountains yielded sediment runoff of 0.06 ton/acre/inch of rainfall, a significant reduction from the 1.475 ton/acre/inch of rainfall yielded by a road surface covered by only 5 cm of crushed rock (Figure 3-9). In another study in the Appalachian mountains, Kochenderfer and Helvey (1984) demonstrated that using 1-inch crusher-run gravel or 3-inch clean gravel reduced erosion from road surfaces to less than one-half of that from 3-inch crusher-run gravel, and to only 12 percent of the erosion rate measured from an ungraveled road surface (Table 3-12). In a more recent study (Johnson and Bronsdon, 1995), a surface of bituminous oil or 15 to 20 cm of gravel reduced erosion rates by as much as 96 percent below that measured from unsurfaced roads (Figure 3-10). In the same study, logging slash left on roads was also found to provide a protective layer and reduced erosion by 75 to 87 percent compared to unsurfaced roads.

Properly shaping a road surface (i.e., insloped, outsloped, or crowned) might not suffice to control drainage adequately, and drainage structures in addition to the relief culverts on insloped and crowned roads might be necessary for drainage control (Moll et al., 1997). Structures such as broad-based dips, turnouts, and cross drains can be used under such conditions, and these BMPs are further discussed below. The proper choice of drainage structure, in combination with the chosen surface shape, and effective installation of the

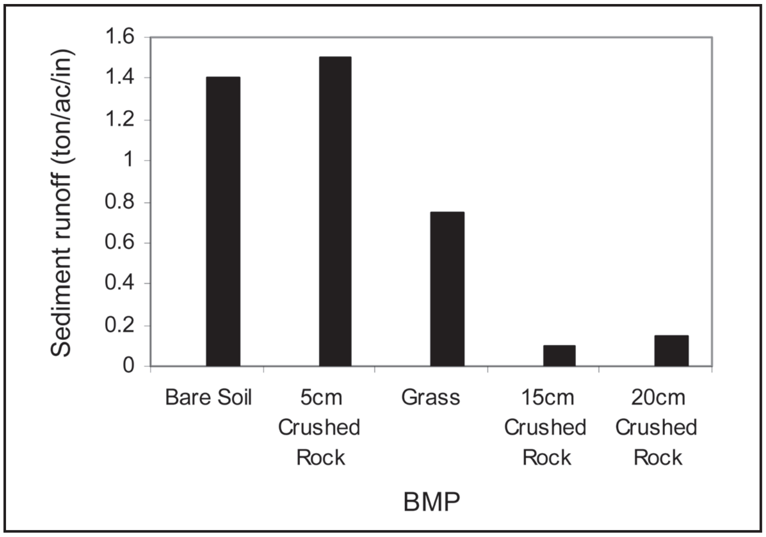

Figure 3-9. Comparison of sedimentation rates (as tons of sediment in runoff per acre per inch of rainfall) from different forest road surfaces (after Swift, 1984).

Table 3-12. Effectiveness of Road Surface Treatments in Controlling Soil Losses in West Virginia (adapted from Kechenderfer and Helvey, 1984)

Surface Treatment	Average Annual Soil Losses (tons/acre)[a]
Ungraveled	44.4
3-inch crusher-run gravel	11.4
1-inch crusher-run gravel	5.5
3-inch clean gravel	5.4

[a] Six measurements taken over a 2-year period.

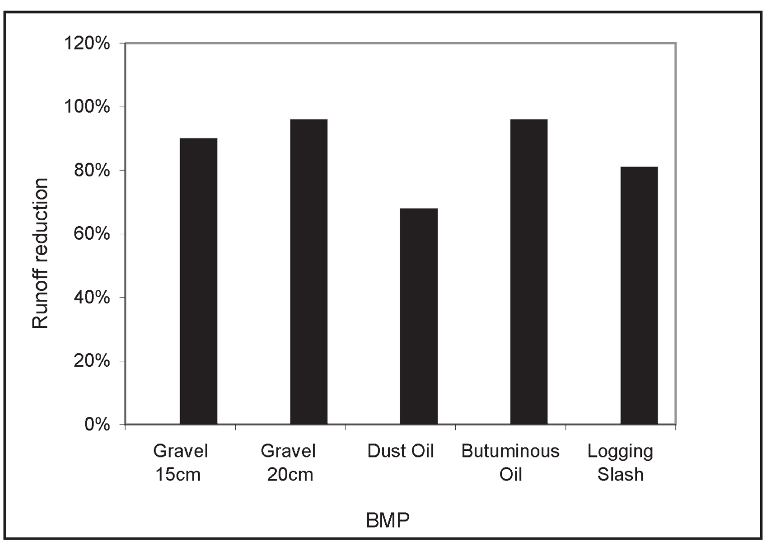

Figure 3-10. Percent of reduction in sediment runoff from a forest road surface with different treatments. Percent reduction in erosion is the amount below that observed on an untreated road (after Johnson and Bronsdon, 1995).

drainage structures is crucial to minimizing erosion from roads and sedimentation in water bodies. Improper or insufficient installation of road drainage structures is the cause of many road failures, whereas proper installation of the correct structure can reduce erosion potential, extend the useful life of a road, and decrease the need for road maintenance.

Slope Stabilization

Road cuts and fills can be a large source of sediment once a logging road is constructed. Stabilizing back slopes and fill slopes as they are constructed is an important process in minimizing erosion from these areas. Combined with graveling or otherwise surfacing the road, establishing grass or using another form of slope stabilization can significantly reduce soil loss from road construction. If constructing on an unstable slope is necessary, as it sometimes is, consider consulting with an engineering geologist or geotechnical engineer for recommended construction methods and to develop plans for the specific road segment. Unstable slopes that threaten water quality should always be considered unsuitable for road building (Weaver and Hagans, 1984).

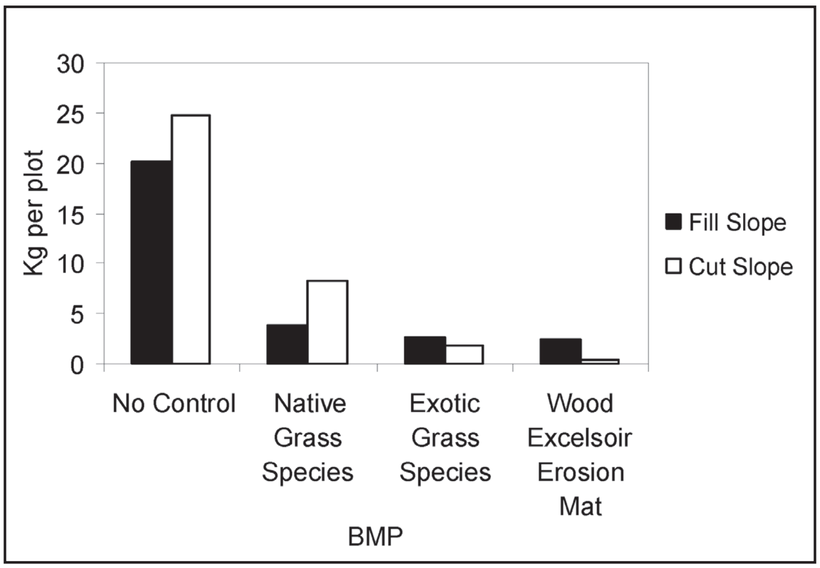

Figure 3-11. Sediment yield from plots using various forms of ground covering. Sediment yield is per plot area over a 6-month period; plots measured 1.5 m x 3.1 m (after Grace et al., 1998).

Planting grass on cut-and-fill slopes of new roads can effectively reduce erosion, and placing forest floor litter or brush barriers on downslopes in combination with establishing grass is also an effective means to reduce downslope sediment transport (Tables 3-13 and 3-14). Grass-covered fill is generally more effective than mulched fill in reducing soil erosion from newly constructed roads because of the roots that hold the soil in place, which are lacking with any other covering placed on the soil. Because grass needs some time to establish itself, a combination of straw mulch with netting to hold it in place can be used to cover a seeded area and effectively reduce erosion during the period while grass is growing. The mulch and netting provide immediate erosion control and promote growth of the grass. Figure 3-11 shows the results of a study conducted by Grace and others (1998) to demonstrate the erosion control capacities of different cut-and-fill slope stabilization BMPs on forest roads. The results of several studies on different types of slope stabilization BMPs are summarized in Table 3-15.

Table 3-13. Reduction in the Number of Sediment Deposits More Than 20 Feet Long by Grass and Forest Debris (Swift, 1986)

Type of Soil Protection	Degree of Soil Protection	Number of Deposits per 1,000 Feet of Road
Grassed fill, litter and brush burned	Low	13.9
Bare fill, forest litter		9.9
Mulched fill, forest litter	↕	8.1
Grassed fill, forest litter, no brush barrier		6.9
Grassed fill, forest litter, brush barrier	High	4.5

Table 3-14. Comparison of Downslope Movement of Sediment from Roads for Various Roadway and Slope Conditions (Swift, 1986)

Comparisons	Sites (no.)	Mean Slope (%)	Distance (feet)		
			Mean	Max	Min
All sites	88	46	71	314	2
Barrier[a]					
Brush barriers	26	46	47	156	3
No brush barrier	62	47	81	314	2
Drainage[b]					
Culvert	21	40	80	314	30
Outsloped without culvert	56	47	63	287	2
Unfinished roadbed with berm	11	57	95	310	25
Grass fill and forest litter[c]	46	40	45	148	2
With brush barrier	16	39	34	78	3
With culvert	4	20	37	43	30
Without culvert	12	45	32	78	3
Without brush barrier	30	41	51	148	2
With culvert	7	37	58	87	30
Without culvert	23	42	49	148	2

[a] Examined the effectiveness of leaving brush barriers in place below road fills, rather than removing brush barriers.
[b] Compared roads where storm water was concentrated at a culvert pipe to outsloped roads without a culvert. The berm was constructed on an unfinished roadbed to prevent downslope drainage.
[c] Compared effectiveness of brush barriers versus drainage (culvert) systems.

Table 3-15. Effectiveness of Surface Erosion Control on Forest Roads (adapted from Megahan, 1980, 1987)

Stabilization Measure	Portion of Road Treated	Percent Decrease in Erosion[a]	Reference
Hydro-mulch, straw mulch, and dry seeding[b]	Fill slope	24 to 58	King, 1984
Tree planting	Fill slope	50	Megahan, 1974b
Wood chip mulch	Fill slope	61	Ohlander, 1964
Straw mulch	Fill slope	72	Bethlahmy and Kidd, 1966
Excelsior mulch	Fill slope	92	Burroughs and King, 1985
Paper netting	Fill slope	93	Ohlander, 1964
Asphalt-straw mulch	Fill slope	97	Ohlander, 1964
Straw mulch, netting, and planted trees	Fill slope	98	Megahan, 1974b
Straw mulch and netting	Fill slope	99	Bethlahmy and Kidd, 1966
Straw mulch	Cut slope	32 to 47	King, 1984
Terracing	Cut slope	86	Unpublished data[c]
Straw mulch	Cut slope	97	Dyrness, 1970
Wood chip mulch	Road fills	61	Bethlahmy and Kidd, 1966
Straw mulch	Road fills	72	Ohlander, 1964
Grass and legume seeding	Road cuts	71	Dyrness, 1970
Gravel surface	Surface	70	Burroughs and King, 1985
Dust oil	Surface	85	Burroughs and King, 1985
Bituminous surfacing	Surface	99	Burroughs and King, 1985

[a] Percent decrease in erosion compared to similar, untreated sites.
[b] No difference in erosion reduction between these three treatments.
[c] Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Boise, ID, nd.

Road Construction, Fish Habitat, Stream Crossings, and Fish Passage

Chapter 2 discusses how road construction and road use can cause sediment to be delivered to streams, and it reviews the water quality and fish passage problems associated with sediment and stream crossings. The quality of surface waters to support early life stages of fish can be degraded by nonpoint source pollution from forestry activities as well. Salmonids and other fish that nest on stream bottoms are very susceptible to sediment pollution due to the settling of sediment that can smother nests and deplete the oxygen available to the eggs. The eggs, buried 1 to 3 feet deep in the gravel redd, rely on a steady flow of clean, cold water to bring oxygen and remove waste products. In coastal streams, eggs hatch in a month or so, depending on water temperatures and species of fish. Eggs hatch into alevin and remain in the gravel another 30 days or so, living on the nutrients in their yolk sacs. As they develop into fry, the yolk gets used up, and fry emerge through spaces in the gravel to begin life in the stream. During the 60-day period when the eggs and alevin are in the gravel, any shifts of the stream bottom can kill them.

Recent studies in streams on the Olympic Peninsula in Washington found that if more than 13 percent fine sediment (< 0.85 mm) intruded into the redd, no steelhead or coho salmon eggs survived (McHenry et al., 1994). Chinook salmon are the most susceptible to increased fine sediment, followed by coho salmon, steelhead, and cutthroat trout, respectively (Lotspeich and Everest, 1983). The different tolerances to fine sediment is due to the different head diameters of the fry of the species.

The predominant source of sediment from logging is from the construction and maintenance of access roads.

The redd is a depression in the gravel streambed where the eggs are laid, and the depression creates a Venturi effect, drawing water down into the gravel. If the water in the stream above is full of fine sediment, the sediment is drawn down into the redd and smother the eggs.

In a healthy stream, young salmon and trout hide in the interstitial spaces between cobbles and boulders to avoid predation. In streams that become extremely cold in winter, young steelhead may actually burrow into the streambed and spend the winter in flowing water down within the gravel. The area of the stream where flowing water extends down into the gravel is also extremely important for aquatic invertebrates, which supply most of the food for young salmon, steelhead, and cutthroat trout. If fine sediment is clogging interstitial spaces between streambed gravel, juvenile salmonids lose their source of cover and food.

During the year coho salmon spend in freshwater, they prefer pools. High sediment concentrations in the water can cause pools to fill with sediment and reduce or destroy essential coho rearing habitat. Case studies in southwest Oregon showed that streams damaged by logging can also have significant problems with mortality of salmon eggs and alevin (Nawa and Frissell, 1993). When streams are affected by high sediment deposition, these formerly productive low-gradient reaches become wide and shallow and recovery of fish habitat can take decades (Frissell, 1992).

A fishway is any structure or modification to a natural or artificial structure for the purpose of fish passage. Five common conditions at stream crossing culverts create migration barriers (WADOE, 1999):

- Excess drop at culvert outlet

- High velocity within culvert barrel
- Inadequate depth within culvert barrel
- Turbulence within the culvert
- Debris accumulation at culvert inlet

Figure 3-12 illustrates four of these conditions. Barriers to fish passage can be complete, partial, or temporal. Complete barriers block the use of the upper watershed, often the most productive spawning habitat in the watershed for migratory species of fish. Partial barriers block smaller or weaker fish of a population. Culverts are therefore designed to accommodate smaller or weaker individuals of target species, including juvenile fish. Temporal barriers block migration during some part of the year. Fish passage can be provided in streams that have wide ranges of flow by providing multiple culverts (Figure 3-13). They can delay some fish from arriving at upstream locations, which for some fish (anadromous salmonids that survive a limited amount of time in fresh water) can cause limited distribution or mortality (WADOE, 1999). The FishXing Web site (http://www.stream.fs.fed.us/fishxing/index.html) provides software and learning systems for fish passage through culverts.

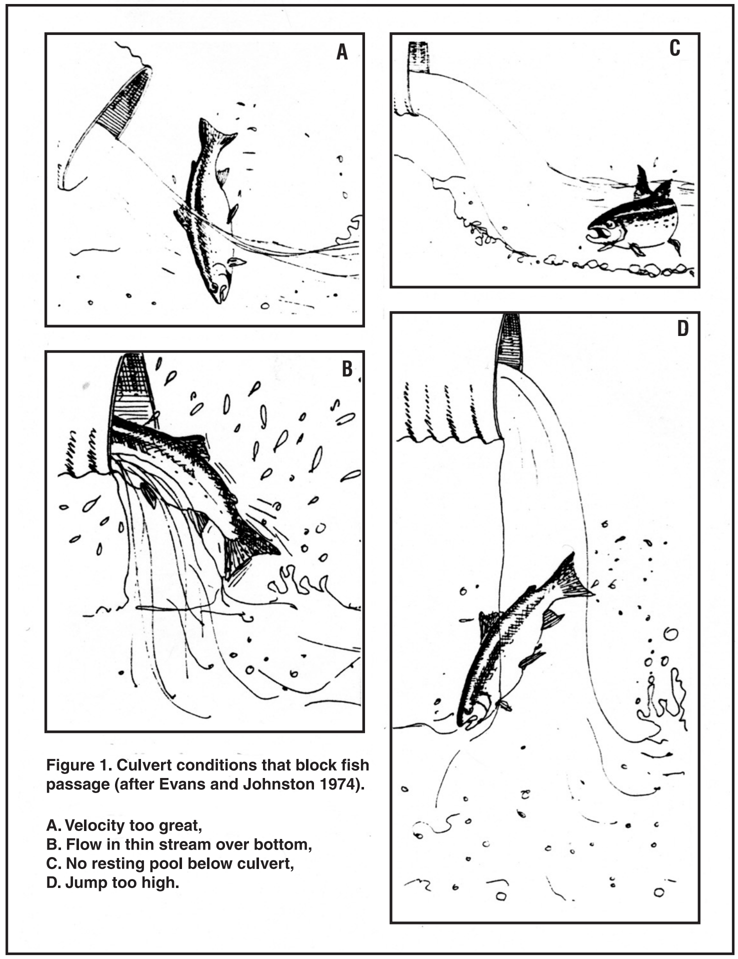

Figure 3-12. Culvert conditions that block fish passage (Yee and Roelofs, 1980).

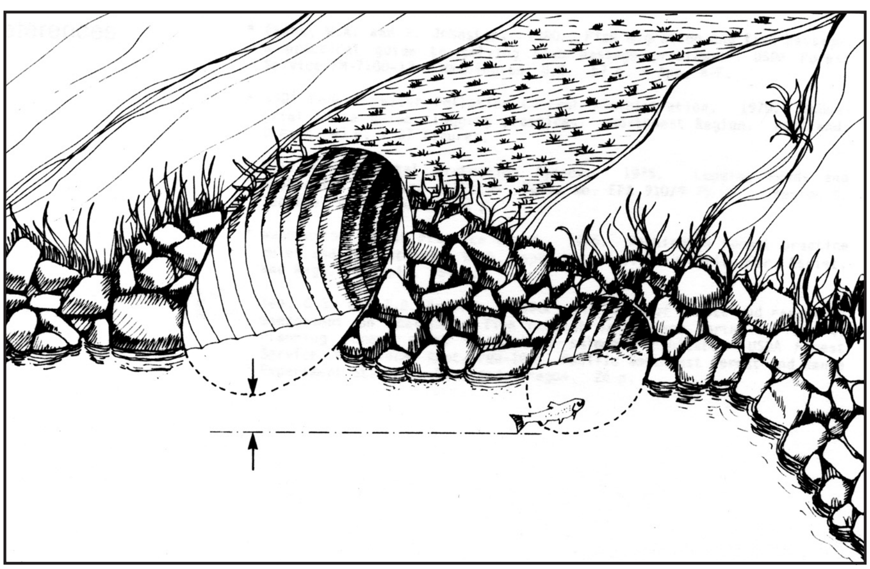

Figure 3-13. Multiple culverts for fish passage in streams that have a wide range of flows (Hyson et al., 1982).

Stream Crossing Considerations

- Whether fish use the channel at the crossing site
- Whether the crossing will be temporary or permanent
- The type of vehicles that will use the crossing
- The slope, configuration, and stability of the natural hillslopes on either side of the channel
- The slope of the channel bed
- The orientation of the stream to the proposed road
- The expected 50- and 100-year flood discharge
- The amount and type of sediment and woody debris that is in transport within the channel
- The installation and subsequent maintenance costs for the crossing
- The expected frequency of use
- Permits and other legal requirements

(Source: Weaver and Hagans, 1984)

Barriers at culverts can result from improper initial design or installation, or they can be the result of channel degradation that leaves culvert bottoms elevated above the downstream channel. Changes in hydrology due to an extensive road network can be a primary reason for channel degradation, and older culverts that might have been adequate when installed can become inadequate for fish passage when channel degradation or land use changes cause changes in stream channel hydrology (Baker and Votapka, 1990; WADOE, 1999). When such changes occur in a watershed, inspect culverts and, if necessary, replaced them with ones that meet actual specifications.

Other problems at culverts include their not providing the roughness and variability of the adjacent stream channel bottom, which can create short distances of increased water velocity and turbulence (WADOE, 1999). These problems create barriers to the upstream migration of juvenile fish. Fish will not travel upstream under high water velocity conditions (Barber and Downs, 1996).

Water velocity in culverts is a complex issue, involving the length of the culvert in relation to fish capabilities, depth of water, icing and debris flows, and design flows in relation to fish migration upstream or downstream. The size and species of fish passing through a culvert and the magnitude, duration, frequency, and seasonal relationship of the flow to the timing of fish movement have to be considered in setting guidelines for culvert design to meet fish passage requirements (Ashton and Carlson, 1984; Baker and Votapka, 1990).

The addition of baffles to a culvert to affect water velocity and turbulence is not generally recommended because of the regular cleaning that becomes necessary. In addition, it has been found that turbulence at the edge of a baffled culvert actually creates a blockage to fish passage, and in higher-velocity culverts passage success can be higher in smooth pipe (Bates, 1994; Powers, 1996).

Countersunk culverts are recommended where fish passage is desired. Installation of multiple, parallel culverts in place of a larger single culvert is discouraged except in special cases, such as to permit fish passage where flows vary widely (see Figure 3-9). Countersunk culverts allow for natural downstream transport of sediment and a natural stream bottom within the culvert (White, 1996).

Wetland Road Considerations

Sedimentation is also a concern when considering road construction through wetlands. Because of the fragility of these ecosystems, where an alternative route exists, avoid putting a forest access road through a wetland. If it's necessary to traverse a wetland, implement the BMPs suggested by the state. In addition, if road construction or maintenance involves a discharge of dredged or fill material into wetlands or other waters of the United States, section 404(f) requires the application of specific BMPs designed to protect the aquatic environment. (More information on wetlands and forestry, including a list of the aforementioned BMPs, is provided in Chapter 3, section J.)

Benefits of Road Construction Practices

Many states have found roads to consistently be sources of sediment discharge to streams. The Vermont Agency of Natural Resources assessed BMP implementation and effectiveness and found that roads were consistently the most problematic with respect to proper BMP implementation. Drainage ditches, culverts, and stream crossings were most frequently the points of origin of stream sedimentation. The Virginia Department of Forestry also found that water control structures on roads are often inadequately used and applied. The Department found that water bars, rolling dips, and broad-based dips were usually installed improperly. Water bars, for instance, were built using fill only, rather than by cutting into the road bed and then using fill material to shape the bar. These structures were often placed too infrequently and too far apart as the road grade increased, and in some cases they were installed backwards, being angled uphill with the outlet pointing upslope.

The Montana Department of Natural Resources and Conservation, Forestry Division, also monitored BMP implementation and effectiveness and similarly found that the most frequent departures from BMP implementation standards and sources of effects were associated with providing adequate road surface drainage, routing road drainage through adequate filtration zones before the runoff entered a stream, maintaining erosion control structures, and providing energy dissipaters at drainage structure outlets. The division also found that high-risk BMPs were more frequently not applied properly, and water quality effects from them were common.

The Virginia Department of Forestry assessed BMP implementation and effectiveness in 1994 and concluded from the study that although improvement was needed in meeting minimum standards of BMP implementation, properly implemented stream crossings (as well as SMAs and preharvest plans) are crucial to protecting water quality. Where not implemented properly, stream crossings are less effective than they could be. Improper sizing, placement, and installation of culverts are the causes of most failures. Culverts often were found to be too short for the intended roadbed width, and consequently they became clogged or buried. Some culverts were placed improperly, and without correction could have been rendered ineffective or swept away by storm water cutting through fill material.

In general, poor BMP effectiveness can be due to many factors, including the following:

- A lack of time or willingness to plan timber harvests carefully before cutting begins.
- A lack of skill in or knowledge of designing effective BMPs.
- A lack of equipment needed to implement effective BMPs.
- The belief that BMPs are not an integral part of the timber harvesting process and can be engineered and fitted to a logging site after timber harvesting has been completed.
- A lack of timely implementation and maintenance of BMPs.

Road Construction and Stream Crossing BMP Costs

Costs of forestry BMPs for water quality protection are difficult to specify because the need for and design of BMPs varies from site to site with changes in topography, soil, and proximity to water, among other factors. However, with respect to road construction BMPs, some generalizations can be made. In a study of the costs of various forestry practices in the southeastern United States, practices associated with road construction were generally found to be the most expensive, regardless of terrain, and the costs for broad-based dips and water bars increased as slope increased (Lickwar, 1989) (Table 3-16). The proximity of roads to watercourses also increases the cost of road construction because of the increased need to prevent sediment runoff from reaching the surface waters.

Unit cost comparisons for road surfacing practices (Swift, 1984a) revealed that grass is the least expensive alternative at $272 per kilometer of road (1998 dollars) (Table 3-17). Initial material costs alone, however, are misleading because a durable road surface can endure several years of use, whereas a grassed or thinly graveled surface will generally need regular maintenance and resurfacing. Grass and thin gravel coverings are also likely to result in more erosion and sedimentation. Table 3-18 compares the cost of using a single BMP (dry seeding alone) versus using multiple BMPs (seeding in conjunction with plastic netting) to control erosion (Megahan, 1987).

Table 3-16. Cost Estimates (and Cost as a Percent of Gross Revenues) for Road Construction (Lickwar, 1989)

Practice Component	Location					
	Steep Sites[a]		Moderate Sites[b]		Flat Sites[c]	
Stream crossings	$45	(0.01%)	$185	(0.03%)	$4,303	(0.33%)
Broad-based dips	$16,550	(2.88%)	$10,101	(1.49%)	$4,649	(0.36%)
Water bars	$12,225	(2.13%)	$6,371	(0.94%)	$2,999	(0.24%)
Added road costs	$5,725	(1.00%)	Not provided		Not provided	

Note: All costs updated to 1998 dollars.
[a] Based on a 1,148-acre forest and gross harvest revenues of $399,685. Slopes average over 9 percent.
[b] Based on a 1,104-acre forest and gross harvest revenues of $473,182. Slopes ranged from 4 percent to 8 percent.
[c] Based on a 1,832-acre forest and gross harvest revenues of $899,491. Slopes ranged from 0 percent to 3 percent.

Table 3-17. Cost of Gravel and Grass Road Surfaces (North Carolina, West Virginia) (Swift, 1984a)

Surface	Quantity/km	Unit Cost	Total Cost/km
Grass	28 kg Ky-31 14 kg rye 405 kg 10-10-10 900 kg lime Labor and equipment	$1.32/kg $1.03/kg $0.189/kg $0.052/kg $97.49/km	$36.90 $14.50 $76.89 $46.59 $97.49
Crushed rock (5 cm)[a]	425 ton	$7.34/ton	$3,120
Crushed rock (15 cm)[a]	1,275 ton	$7.34/ton	$9,361
Large stone (20 cm)[a]	1,690 ton	$8.22/ton	$13,893

Note: All costs updated to 1998 dollars.
[a] Values in parentheses are thickness or depth of surfacing material.

Table 3-18. Costs of Erosion Control Measures in Idaho (Megahan, 1987)

Measure	Cost ($/acre)
Dry seeding	$178
Plastic netting placed over seeded area	$8,124

Best Management Practices

Road Surface Construction Practices

◆ Follow the design developed during preharvest planning to minimize erosion by properly timing and limiting ground disturbance operations.

Verify with site visits that information used during preharvest planning to develop road layout and surfacing designs is accurate. Make any changes to road and road surface construction designs that are necessary based on new information obtained during these site visits.

◆ *During road construction, operate equipment to minimize unintentional movement of excavated material downslope.*

◆ *Properly dispose of organic debris generated during road construction.*

- Stack usable materials such as timber, pulpwood, and firewood in suitable locations and use them to the extent possible. Organic debris can be used as mulch for erosion control, piled and burned, chipped, scattered, place in windrows, or removed to designated sites. Slash can be useful if placed as windrows along the base of the fill slope. A windrow is created by piling logging debris and unmerchantable woody vegetation in rows on the contour of the land. Arranged in this manner, the slash material provides a barrier to overland flow, prevents the concentration of runoff, and reduces erosion.
- Don't use organic debris as fill material for road construction since the organic material eventually decomposes and causes fill failure.
- Perform any work in the stream channel by hand to the extent practicable. Machinery can be used in the SMA as long as the desired SMA objective is not compromised.

◆ *Prevent slash from entering streams and promptly remove slash that accidentally enters streams to prevent problems related to slash accumulation.*

To the extent possible, prevent slash from entering streams. If allowed to stay in streams, it can cause flow or fish passage problems, or dissolved oxygen depression as it decomposes. Leave natural debris in stream channels, and remove only that slash that is contributed during road construction or harvesting. Large woody debris is an important source of energy for aquatic organisms, especially in smaller headwater streams, and it creates habitat diversity important to aquatic invertebrates and young fish. It is important, therefore, to inspect streams before any work is done near them and to attempt to leave them in a condition similar to that prior to the work.

◆ *Compact the road base at the proper moisture content, surfacing, and grading to give the designed road surface drainage shaping.*

The predominant source of sediment associated with forest harvesting is the construction and maintenance of access roads, which contribute as much as 90 percent of the total eroded sediments (Appelbloom et al., 1998). The annual production of sediment from roads can be as high as 100 tons per hectare (40.5 tons per acre) of road surface or more (Grayson et al., 1993; Kockenderfer and Helvey, 1984). Management practices, including gravel surfacing, proper road maintenance, and proper drainage control, can reduce sediment loss. Gravel surfacing has to be of a sufficient depth (e.g., 15–20 cm). Improperly maintained roads can produce up to 50 percent more sediment than properly maintained roads. Since roads can produce large quantities of sediment even when they are well maintained, careful consideration of their placement and management is extremely important to minimizing their effects on water quality.

◆ *When soil moisture is high, promptly suspend earthwork operations and weatherproof the partially completed work.*

Regulating traffic on logging roads during unfavorable weather is an important phase of erosion control. Construction and logging under these conditions destroy drainage structures, plug up culverts, and cause excessive rutting, thereby increasing the amount and the cost of maintenance.

◆ *Consider geotextiles for use on any section of road requiring aggregate material layers for surfacing.*

Geotextile is a synthetic permeable textile material used with soil, rock, or any other geotechnical engineering-related materials (Wiest, 1998). Also known as geosynthetics, geotextiles are associated with high-standard all-season roads, but can also be used in low-standard logging roads. Geotextiles have three primary functions: drainage (filtration), soil separation (confinement), and soil reinforcement (load distribution). These functions are performed separately or simultaneously, but not all functions are provided by each type of geotextile, so use care when making a purchase. Geotextiles reduce the amount of aggregate needed, thus reducing the cost of the road (Wiest, 1998).

The location of a geotextile along a forest road does not affect installation procedures. When installing geotextiles, proper procedure includes the following steps:

- Clear the subgrade of sharp objects, stumps, and debris.
- Grade the surface to provide proper drainage and cross-slope shaping.
- Unroll the geotextile on the subgrade. The amount of overlap depends on the load-bearing capacity of the subgrade, and varies from 1.5 to 3 feet. Sewing may be necessary if the geotextile is to provide reinforcement.
- Place and compact the aggregate fill. Depth of the aggregate is determined by subgrade strength and the anticipated wheel loading (usually between 9 and 24 inches). It might be necessary to back-dump the aggregate onto the geotextile and spread with a dozer or grader. The rock is feathered out, since pushing it onto the site produces an uneven distribution of the aggregate. Spread the aggregate in the same direction as the geotextile overlap to avoid separation.
- Compact the aggregate by conventional methods.

Streambanks and other slopes with light wave action can be stabilized by placing the revetment material directly on top of the geotextile. Installing the geotextile underneath the revetment material prevents the occurrence of scour which normally takes place along streambanks behind BMPs such as rip-rap. To ensure that the geotextile stays in place, toe it in at the top and bottom.

Geotextiles extend the service life of roads, increase their load-carrying capacity, and reduce the incidence of ruts. These benefits are realized due to the textiles separating aggregate structural layers from subgrade soils while allowing the passage of water.

◆ *Protect access points to the site that lead from a paved public right-of-way with stone, wood chips, corduroy logs, wooden mats, or other material to prevent soil or mud from being tracked onto the paved road.*

This practice prevents tracking of sediment onto roadways, thereby preventing the subsequent washoff of that sediment during storm events. When necessary, clean truck wheels to remove sediment before entering a public right-of-way.

◆ *Use pioneer roads to reduce the amount of area disturbed and ensure the stability of the area involved.*

Pioneer roads are temporary access ways used to facilitate construction equipment access when building permanent roads. Confine pioneer roads to the construction limits of the surveyed permanent roadway, and it is important that pioneer roads be fitted with temporary drainage structures to prevent erosion, sedimentation, and road deterioration.

◆ *If the use of borrow or gravel pits is needed during forest road construction, locate rock quarries, gravel pits, and borrow pits outside SMAs and above the 50-year flood level of any waters to minimize the adverse effects caused by the resulting sedimentation. Avoid excavating below the water table.*

Gravel mining directly from streams causes a multitude of effects, including destruction of fish spawning sites, turbidity, and sedimentation. During the construction and use of rock quarries, gravel pits, or borrow pits, either divert runoff water onto the forest floor or pass it through one or more settling basins. Revegetate and reclaim rock quarries, gravel pits, spoil disposal areas, and borrow pits upon abandonment.

Road Surface Drainage Practices

◆ *Install surface drainage controls at intervals that remove storm water from the roadbed before the flow gains enough volume and velocity to erode the surface. Avoid discharge onto fill slopes unless the fill slope has been adequately protected. Route discharge from drainage structures onto the forest floor so that water disperses and infiltrates. Methods of road surface drainage include the following:*

- *Broad-based dips*. A broad-based dip is a gentle roll in the centerline profile of a road that is designed to be a relatively permanent and self-maintaining water diversion structure that can be traversed by any vehicle (Figure 3-14). Outslope dips 3 percent to divert storm water off the roadbed and onto the forest floor, where transported soil can be trapped by forest litter. Use broad-based dips on roads having a gradient of 10 percent or less because on steeper grades they can be difficult for loaded trucks to traverse

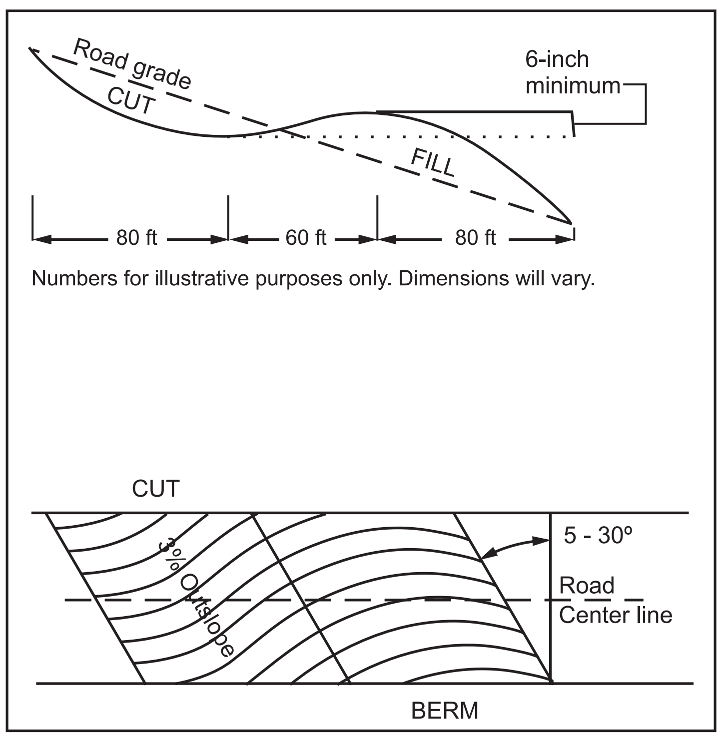

Figure 3-14. Broad-based dip installation. A broad-based dip is a portion of road sloped to carry water from the inside edge to the outside onto natural ground (Minnesota DNR, 1995; Montana State University, 1990).

(Kochenderfer, 1995). Dips can be difficult to construct on very rocky sections of roads as well.

- *Road outsloping, Insloping, Crowning, and Grading*. Water accumulation on road surfaces can be minimized by grading and insloping or outsloping roadbeds (Figure 3-15). This minimizes erosion and the potential for road failure. Outsloping involves grading a road so that the entire width of the road slopes down the hill it is cut into, and it is appropriate when fill slopes are stable and drainage won't flow directly into stream channels. Outsloping the roadbed keeps water from flowing next to and undermining the cutbank, and it is intended to spill water off the road in small volumes along its length. Give the width of the road a 2 to 3 percent outslope. In addition to outsloping the roadbed, construct a short broad-based dip to turn water off the surface. The effectiveness of outsloping is limited by roadbed rutting during wet conditions. Providing a berm on the outside edge of an outsloped road during construction, and until loose fill material is protected by vegetation, can eliminate erosion of the fill. A continuous berm (i.e., a low mound of soil or gravel built along the edge of a road) along a roadside can reduce total sediment loss by an average of 99 percent over a standard graded soil road surface (Applebloom et al., 1998). Berms need to have openings provided to allow water to drain off the road surface at appropriate locations where a suitable infiltration or sediment trap site is reached (Swift and Burns, 1999). Construct berms high enough to contain the storm water, and wide enough and with a coarse material to prevent their erosion. Berms are also installed over culvert crossings to prevent runoff from draining directly into streams. A graveled road surface or a grassed strip on the edge of the driving surface can reduce total loss of sediment from roads by up to 60 percent over a standard graded soil road surface. Also, natural berms can form along the edge of older roadbeds or at

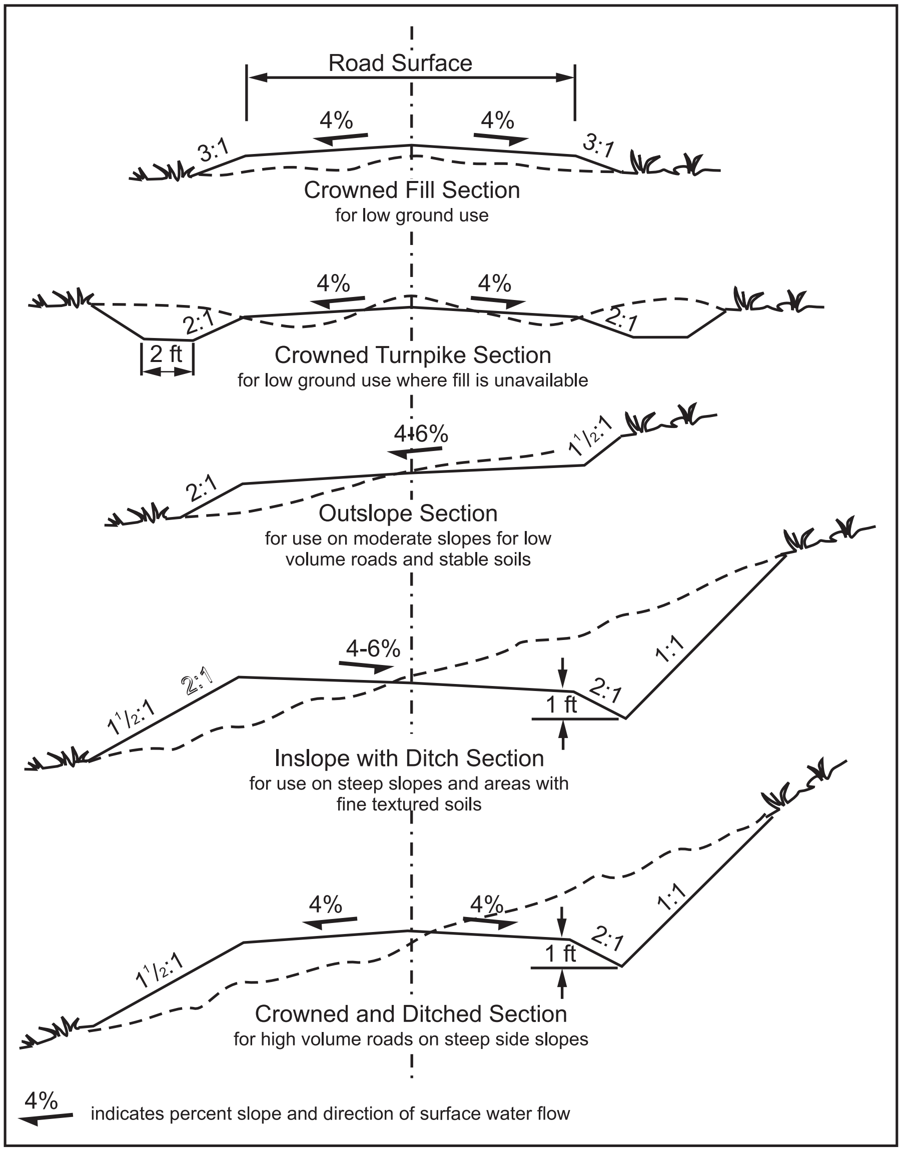

Figure 3-15. Typical road profiles for drainage and stability. Choice of cross section depends on drainage needs, soil stability, slope, and expected traffic volume. Dashed lines indicate natural land contour and solid lines indicate constructed road (Wiest, 1998).

drainage locations on constructed berms over time and block drainage. Proper maintenance, therefore, is necessary.

Insloped roads carry road surface water to a ditch along the cutbank. Ditch gradients of between 2 and 8 percent usually perform best. Slopes greater than 8 percent give runoff waters too much momentum and enough erosive force to carry excessive sediment and debris for long distances, and slopes of less than 2 percent tend to cause water to drain too slowly and do not provide the runoff with enough energy to move accumulated debris with it. The ditch grade also depends on the soil type—nearer to 2 percent on less stable soils and nearer to 8 percent on stable soils.

A crowned road surface is a combination of both an outsloped and insloped surface with the high point (crown) at the center of the road (Moll et al., 1997). The crowned road provides drainage to both sides of the roadway, and a drainage ditch is usually placed next to the road on the insloped side. Properly spaced and sized culverts then direct the runoff to an appropriate grassed buffer, detention basin, or other sediment control structure.

- *Relief culverts*. Relief culverts move water from an inside ditch to the outside edge of a road for dispersion. The culverts should protrude from both ends at least 1 foot beyond the fill and be armored at inlets to prevent undercutting and at outlets to prevent erosion of fill or cut slopes (Figure 3-16).

Where the slope on the cutslope above a culvert is steep, as is often the case because of the need to cut into the slope to accommodate the culvert opening, soil erosion above culverts and culvert plugging might be a problem. Installing a riser pipe on the inlet end of a culvert with holes or slits cut at a proper height to allow water to enter (which depends on the amount of soil eroding and flow in the ditch) can prevent plugging while allowing runoff drainage. A ditch dam will reinforce the entrance of water into the culvert through the riser holes (Firth, 1992).

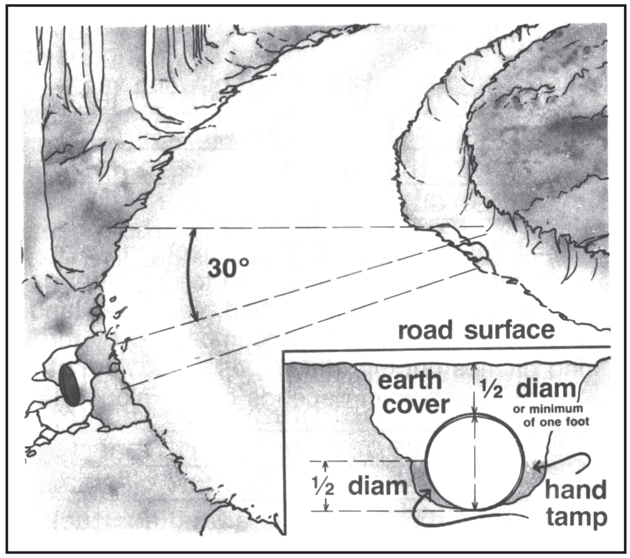

Figure 3-16. Design and installation of relief culvert (Vermont DFPR, 1987).

- *Open-top or pole culverts.* Open-top or pole culverts are temporary drainage structures that are most useful for intercepting runoff flowing down road surfaces (Figure 3-17). They can also be used as a substitute for pipe culverts on roads of smaller operations, if properly built and maintained, but don’t use them for handling intermittent or live streams. Place open-top culverts at angles across a road to provide gradient to the culvert and to ensure that no two wheels of a vehicle hit it at once. For an open-top culvert to function properly, careful installation and regular maintenance are necessary. Open-top culverts are recommended for ongoing operations only and are best removed upon completion of forestry activities (Wiest, 1998). These culverts generally slope below the perpendicular to the road at 10 to 45 degrees. Additional maintenance can be necessary as the angle approaches 10 degrees because at this angle debris tends to accumulate; an angle of 30 to 45 degrees is usually recommended (Wiest, 1998).

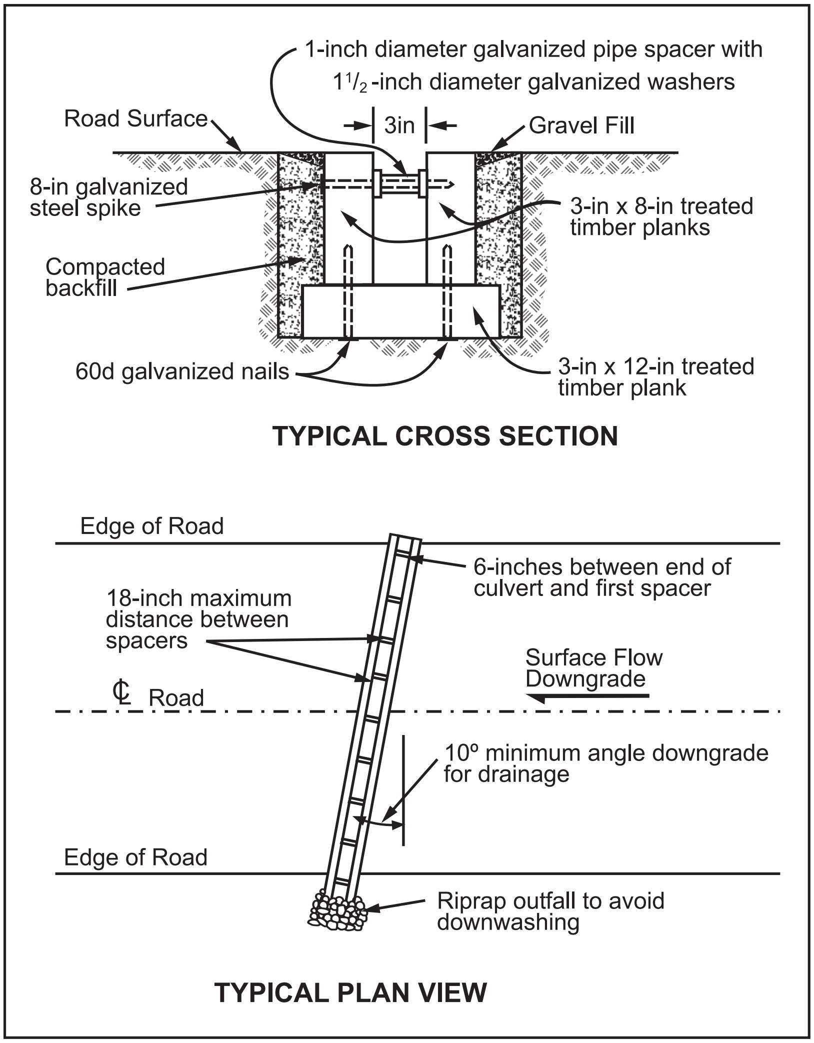

Figure 3-17. Details of installation of open-top and pole culverts (Wiest, 1998; Vermont DFPR, 1987).

Table 3-B.
Spacing of Turnouts

Road Grade *(percent)*	Spacing *(feet)*
2-5	500-300
6-10	300-200
11-15	200-100
16-20	100

Source: *Cooperative Extension Service Division of Agricultural Sciences and Natural Resources, Oklahoma State University*

Figure 3-18. Grading and spacing of road turnouts (Georgia Forestry Commission, 1999).

Open-top culverts constructed of 8-inch or 10-inch pipe are useful as a supplemental means of runoff control on steep sections of roads where broad-based dips are difficult to install and difficult for trucks to traverse (Kockenderfer, 1995). They are also useful on excessively rocky sections of roads where broad-based dips are difficult to construct. Rectangular openings spaced evenly along the top of a piece of pipe direct runoff into the pipe, and unbroken spacings between the openings provide structural integrity. The culverts can be installed by hand and can be removed and used elsewhere when a road is decommissioned. Their trenches are shallower than those for pole culverts. Discharges from all types of culverts can be controlled using plastic corrugated culvert piping cut in half or, where something that blends in with the surroundings is desired, with riprap (Kockenderfer, 1995). Diversions or in-ditch dams can be placed in ditches to ensure that flow in ditches is directed into culverts and it does not bypass culverts and continue to gain momentum and erosive force.

- *Ditches and turnouts*. Use ditches only where necessary to discharge water to vegetated areas via turnouts (Figure 3-18). Turnouts should be used wherever there is an adequate, safe outlet site where the water can infiltrate. In most cases, the less water a ditch carries and the more frequently water is discharged, the better. Construct wide, gently sloping ditches, especially in areas with highly erodible soils. Slow the velocity of water by installing check dams, rock dams that intercept water flow, along the ditch or lining the ditch with rocks. Check dams also trap sediment and need to be inspected for sediment build-up. Additionally, stabilize ditches with rock and/or vegetation and protect outfalls with rock, brush barriers, live vegetation, or other means. Roadside ditches need to be large enough to carry runoff from moderate storms. A standard ditch used on secondary logging roads is a triangular section 45 cm deep, 90 cm wide on the roadway side, and 30 cm wide on the cutbank side. The minimum ditch gradient is 0.5 percent, and 2 percent is preferred to ensure good drainage. Runoff is diverted frequently to prevent erosion or overflow.

◆ *Install turnouts, wing ditches, and dips to disperse runoff and reduce the amount of road surface drainage that flows directly into watercourses.*

◆ *Install appropriate sediment control structures to trap suspended sediment transported by runoff and prevent its discharge into the aquatic environment.*

Methods to trap sediment include the following:

- *Sediment traps*. Sediment traps are used downstream of erodible soil sites, such as cuts and fills, to keep sediment from flowing downstream and entering water bodies (Figure 3-19) (Ontario MNR, 1990). They are located close to the source of sediment and preferably in a low area. Use them for drainage areas of less than 5 acres. Size sediment traps so that the expected sediment runoff fills them at about the time that the disturbed area reestablishes vegetation. If sediment accumulates beyond this time, periodic cleaning becomes necessary. Sediment traps are most effective at removing large sediment particles.
- *Brush barriers*. Brush barriers are slash materials piled at the toe slope of a road or at the outlets of culverts, turnouts, dips, and water bars. Install brush barriers at the toes of fills if the fills are located within 150 feet of a defined stream channel. Brush barriers must have good contact with the ground and be constructed approximately on the contour if they are to be effective in minimizing sediment runoff. Figure 3-20 shows the use of a brush barrier at the toe of fill. Proper installation is important because if the brush barrier is not firmly anchored and embedded in the slope, brush material can be ineffective for sediment removal and can detach to block ditches or culverts. In addition to use as brush barriers, slash can be spread over exposed mineral soils to reduce the effect of precipitation events and surface flow.
- *Silt fences*. Silt fences are temporary barriers used to intercept sediment-laden runoff from small areas. They act as a strainer: silt and sand are trapped on the surface of the fence while water passes through. They usually consist of woven geotextile filter fabric or

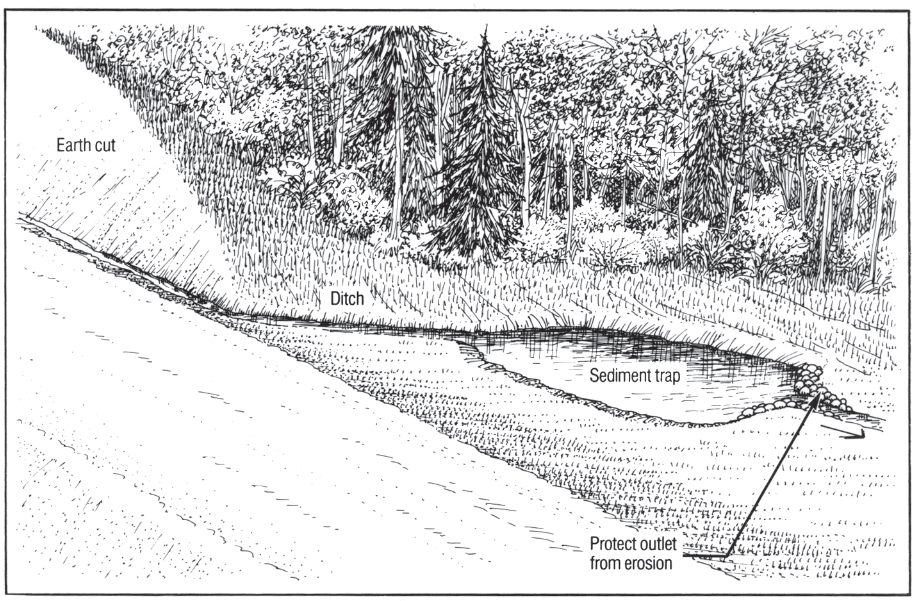

Figure 3-19. Sediment trap constructed to collect runoff from ditch along cutslope (Ontario MNR, 1990).

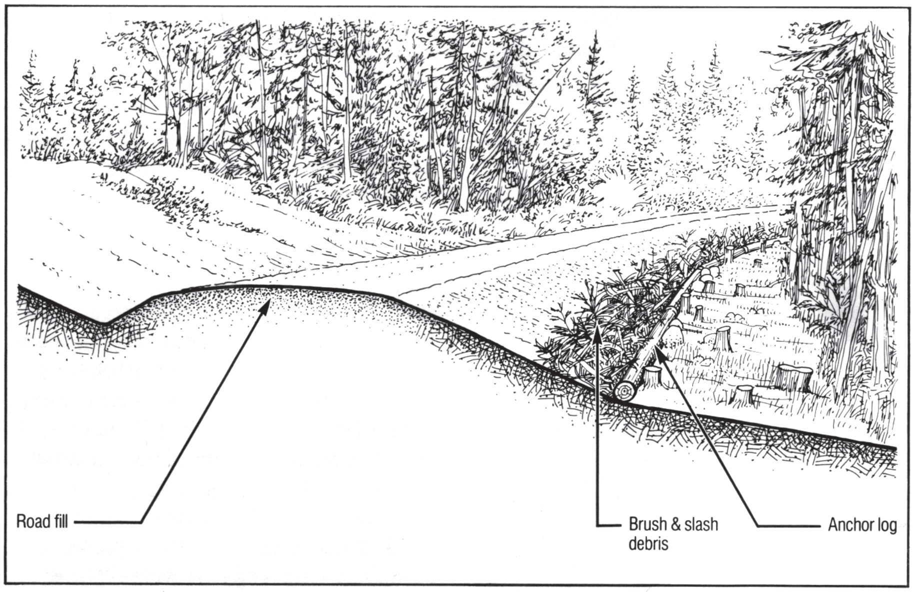

Figure 3-20. Brush barrier placed at toe of fill to intercept runoff and sediment (Ontario MNR, 1990).

straw bales. Install silt fences before earthmoving operations and place them as much along the contour as possible (Figure 3-21).

- *Filter strips*. Sediment control is achieved by providing a filter or buffer strip between streams and construction activities to use the natural filtering capabilities of the forest floor and litter (Figure 3-22). The Streamside Management Area management measure recommends the presence of a filter or buffer strip around all water bodies. Filter strips are effective at trapping sediment only when the runoff entering them is dispersed. Concentrated flows, such as from culverts, ditches, gullies, etc., entering filter strips will tend to cut a path through the filter strip and render it ineffective.

Foresters with the USDA Forest Service working in the Allegheny National Forest in Pennsylvania inspected numerous roads and streams to determine the minimum length of filter strip between the two that was necessary for preventing sediment from reaching the streams (USDA-FS, 1994, 1995). They found that no matter what the slope, filter strips 100 feet in length were the minimum necessary to prevent sedimentation; in more than a few instances, filter strips as long as 200 feet were necessary. In a test of filtering capacities of roadside erosion control techniques in Tuskegee National Forest in Macon County, Alabama, sediment fences retained 29 percent of runoff sediment and vegetative strips

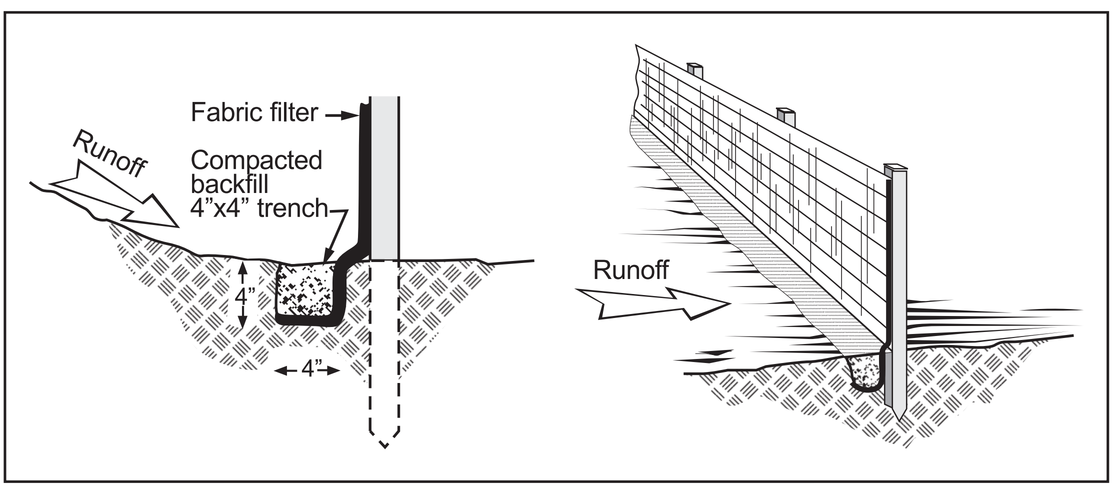

Figure 3-21. Silt fence installation (Wisconsin DNR, 1989).

retained 13.5 percent. Sediment below riprap increased by 10 percent, indicating that riprap has no ability to filter sediment from runoff.

These findings illustrate the importance of both using guidelines developed for the area where the harvest is to occur and inspecting points where runoff is concentrated (e.g., culvert outlets, turnouts) to see if sedimentation controls are sufficient to protect streams. Slope, type of vegetation, ground litter, and nature of flow (channelized or overland) combine to determine how effective filter strips are, and how wide they must be. If sedimentation is found to be occurring despite having installed BMPs according to specifications additional sediment control BMPs might be needed.

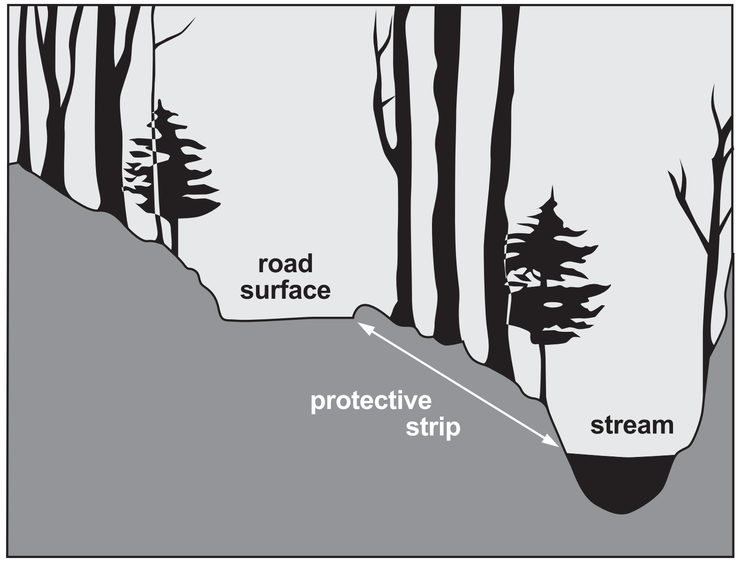

Figure 3-22. Protective filter strip maintained between road and stream to trap sediment and provide shade and streambank stability (Vermont DFPR, 1987).

Road Slope Stabilization Practices

◆ *Visit locations where roads are to be constructed on steep slopes or cut into hillsides to verify that these are the most favorable locations for the roads.*

Aerial photos and topographic and soil maps can inaccurately represent actual conditions, especially if these media are more than a few years old. Visiting a location where roads are to be cut into slopes or built on steep slopes or where skid trails, landings, and equipment maintenance areas are to be located is valuable for verifying that the information used during planning is accurate. Such visits can also help in determining whether roads can be located to pose less risk of erosion than the risk associated with the locations originally chosen.

◆ *Use straw bales, straw mulch, grass seeding, hydromulch, and other erosion control and revegetation techniques to stabilize slopes and minimize erosion (Figure 3-23). Straw bales and straw mulch are temporary measures used to protect freshly disturbed soils and are effective when implemented and maintained until adequate vegetation has established to prevent erosion.*

◆ *Compact the fill to minimize erosion and ensure road stability.*

During construction, fills or embankments are built up by gradual layering. Compact the entire surface of each layer with a tractor or other construction equipment. If the road is to be grassed, do not compact the final layer in order to provide an acceptable seedbed.

◆ *Revegetate or stabilize disturbed areas, especially at stream crossings.*

Cutbanks and fill slopes along forest roads are often difficult to revegetate. Properly condition slopes to provide a seedbed, including rolling embankments and scarifying cut slopes. The rough soil surfaces provide niches in which seeds can lodge and germinate. Seed as soon as it is feasible after the soil has been disturbed, preferably before it rains. Early grassing and spreading of brush or erosion-resisting fabrics on exposed soils at stream crossings are imperative. See the Revegetation of Disturbed Areas management measure for a more detailed discussion.

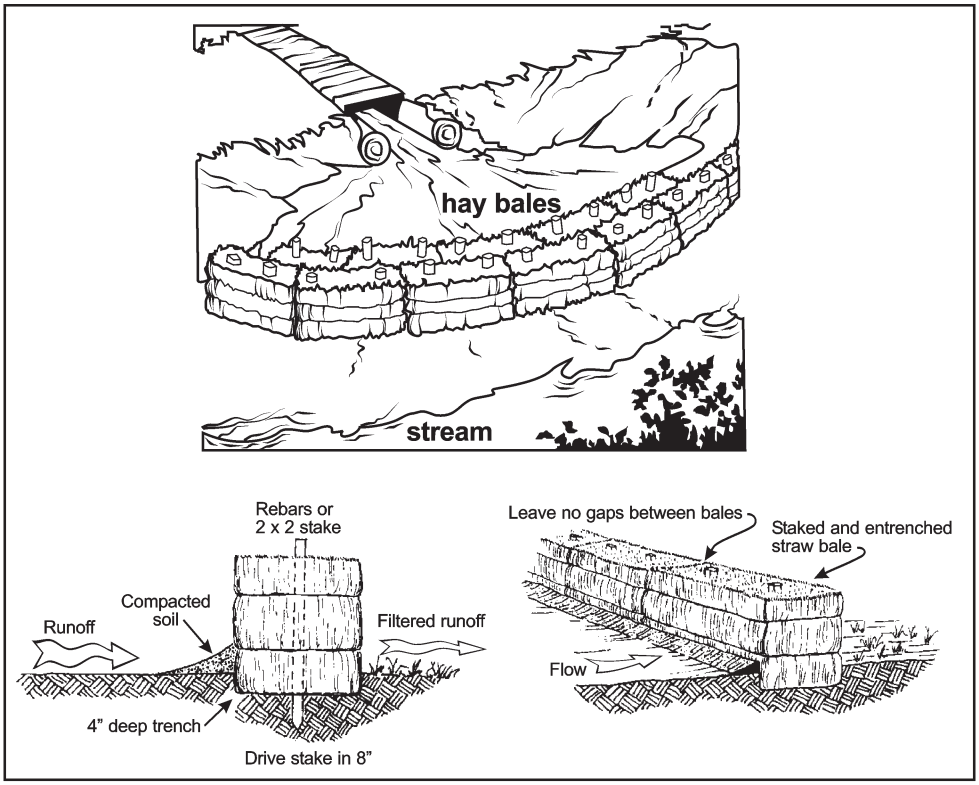

Figure 3-23. Details of hay bale installation, used to prevent sediment from skid trails and roads from entering surface waters (Georgia Forestry Commission, 1999; Vermont DFPR, 1987).

Stream Crossing Practices

◆ *Based on information obtained from site visits, make any alterations to the harvesting plan that are necessary or prudent to protect surface waters from sedimentation or other forms of pollution and to ensure the adequacy of fish passage.*

After preharvest planning has been completed with the aid of aerial photos and/or topographic maps, site visits can be conducted to verify the information used to determine the locations of stream crossings. Photos and maps record the landscape at a moment in time, and changes might have occurred since these media were created. Land use changes in the upper portion of the watershed in which harvesting occurs could have altered streamflow, which in turn might have modified stream corridor characteristics. As a result, alternative stream crossing locations might have to be found. Slopes might be inaccurately represented on topographic maps, and therefore stream crossing approaches or roads near streams might have to be relocated to avoid steep grades, or the width of SMAs might have to be increased. Land use changes in the watershed that increase streamflow or changes in weather patterns (such as numerous recent years of above-average rainfall) that affect streamflow characteristics might call for larger culverts than those originally intended or a switch from fords to culverts or from culverts to temporary bridges to ensure that fish can pass and that stream crossings can adequately handle streamflow. Refer to *Fish Passage Practices* later in this section for further information on constructing stream crossings that ensure adequate fish passage.

◆ *Construct stream crossings to minimize erosion and sedimentation.*

Erosion and sedimentation can be minimized by avoiding any operation of machinery in water bodies. It is especially important to not work in or adjacent to live streams and water channels during periods of high streamflow, intense rainfall, or migratory fish spawning.

Avoid stream crossings whenever practical alternatives are available. When it is necessary to construct stream crossings, install as few of them as possible, select their locations carefully, and select the most appropriate type of stream crossing for the particular site (Blinn et al., 1999). Use existing stream crossings whenever this would affect water quality less than constructing a new one. Make crossings at the narrowest practical portion of a stream and, if possible, cross at a right angle to the stream. Crossing at right angles reduces the potential for sediment to be carried down the road and deposited into the stream during a rain event. If the right angle crossing is too long it is likely to be ineffective. Crossing at right angles is not always practical, particularly in gentle topography. Gentle topography does not accelerate runoff into streams as steep angles do. If there is a gentle grade to a stream, the installation of water turnouts and a broad-based dip on each side of the crossing might suffice. This diverts the majority of the water that is runoff down the road. Avoid sags in grades on stream crossings, as they can cause road runoff to enter the stream (Swift and Burns, 1999). Road grade, whether up or down, should be maintained over the length of the crossing and the runoff diverted from the road at the first feasible location after the crossing.

Diverting a stream from its natural course is a potential problem when any stream crossing is constructed. When the capacity of a culvert under a stream crossing is too small or a culvert becomes plugged, flow is diverted around the culvert (Furniss et al., 1997). The stream might maintain its natural course (flow across the road parallel to the culvert), or, if the road has an inclining grade across the stream crossing in the direction of streamflow or it slopes downward away from a stream crossing in at least one direction, flow is diverted along the road for a distance until it reaches a low point, flows out of the road, and finds a new course to rejoin the original stream course. If left unchecked, such unintentional diversion can result in very large amounts of erosion and sedimentation and long-term adverse effects to roads and aquatic habitats. Stream diversion can also be caused by accumulations of snow and ice on the road that direct water out of the channel. Diversion potential is greatest on outsloped roads that redirect stream water down a road instead of across it (Best et al., 1995).

Stream diversion is best avoided by properly sizing culverts based on streamflow, constructing crossings such that their grade rises away from the crossing at each approach, inspecting stream crossings regularly after their construction, and maintaining roads and stream crossings properly (Bohn, 1998). Eliminating the potential for stream diversion by properly planning, installing, and maintaining roads and stream crossings is, in the long term, much less expensive and straightforward than attempting to correct improper design and installation after a stream crossing fails (Furniss et al., 1997).

◆ *Install a stream crossing that is appropriate to the situation and conditions.*

Determining the stream classification and the type of road to be constructed (e.g., temporary, seasonal, or permanent all-weather) is the first step in defining the type of stream crossing to be installed (Weaver, 1994). Design stream crossings to minimize effect on water quality, to handle peak runoff from flood waters, and to allow for adequate fish passage (where fish could be seasonally present). There are three basic subcategories of both permanent and temporary stream crossings: (1) bridges, (2) fords, and (3) culverts.

- *Bridges*. Temporary or portable bridges are being used increasingly because they can be installed and removed with minimal site disturbance or water quality effect and reused (Figure 3-24) (Taylor et al., 1999). Temporary stream crossings can be constructed of polyvinyl chloride and high-density polyethylene pipe bundles, and portable bridges are often constructed of steel (Blinn et al., 1999; Taylor et al., 1999). Approaches on weak soils can be protected with logs, wood mats, wood panels, or expanded metal grating placed over a woven geotextile.

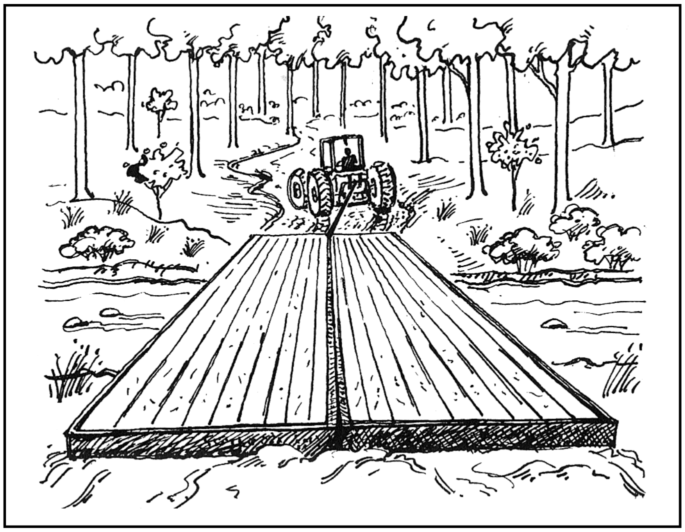

Figure 3-24. Portable bridge for temporary stream crossing (Indiana DNR, 1998).

- *Fords*. A ford is a low-water crossings that uses existing or constructed stream bottoms to support vehicles when crossing a stream (Figure 3-25). A ford is an appropriate stream crossing structure under the following circumstances (Wiest, 1998):
  – The streambed has a firm rock or coarse gravel bottom, and the approaches are low and stable enough to support traffic.
  – Traffic volume is low.
  – Water depth is less than 3 feet.
  – Ford will not prevent fish migration.

If log, coarse gravel, or gabion is used to create a driving surface at a stream ford, install the crossing flush with the streambed to minimize erosion and to allow fish passage. Stabilize approaches to the ford using nonerodible material that extends at least 50 feet from the ford on both sides of the stream crossing.

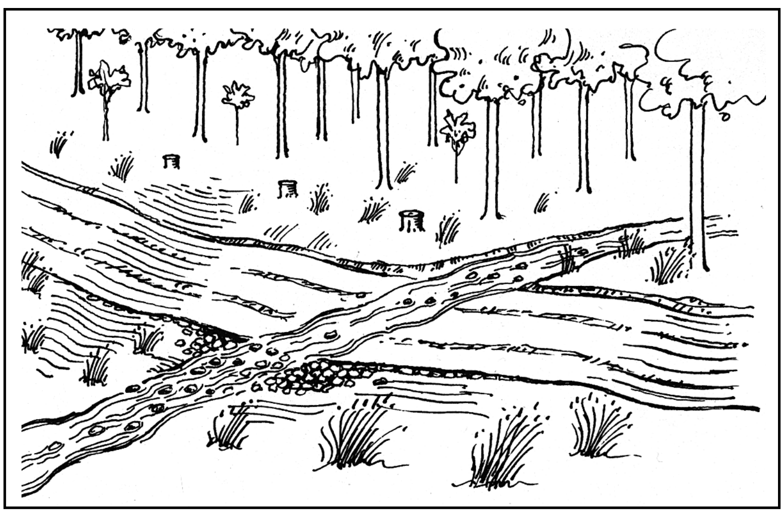

Figure 3-25. A stream ford. Hard and stable approaches to a ford are necessary (Indiana DNR, 1998).

The following is a common procedure for crossing a small stream where a streambed is not armored with bedrock or an otherwise stable foundation:

– Place several inches of rock down on the streambed. The rock size depends on actual costs, haul distance, and how much is to be installed. Normally, 2 feet or more of rock is installed.

– Place geotextiles over the rock. Geotextile costs approximately $550 per 1,000 square yards.

– Spread out approximately 1 foot of gravel. The amount and size of gravel varies with the conditions of the stream crossing.

Unless they are very large, stream fords are often the least expensive stream crossing to construct (Taylor et al., 1999). However, they can have greater effects on water quality than other crossings because sediment is introduced during construction and vehicle crossings. They also permit sediment-laden runoff to flow downslope directly into a stream unless adequate runoff diversions are installed.

- *Stream Crossing Culverts*. Stream crossing culverts are placed on roads where a semi-permanent or permanent stream crossing is necessary and to minimize interference with streamflow and stream ecology. Culverts often need outlet and inlet protection to keep water from scouring away supporting material and to keep debris from plugging the culvert. Firmly anchor culverts and compact the earth at least halfway up the side of the pipe to prevent water from leaking around it (Figure 3-26). Energy dissipaters, such as riprap and slash, can be useful for this if installed at culvert outlets. If riprap is used for inlet protection, a layer of geotextile should be placed behind the riprap to prevent erosion. Culvert spacing depends on rainfall intensity, drainage area, topography, and amount of forest cover. Most state forestry departments can provide recommendations for culvert pipe diameters.

According to Murphy and Miller (1997), culverts should be able to handle large flows—at least the 50-year flood. The larger the drainage area leading to a culvert and the steeper the topography, the larger the culvert needs to be to adequately handle the storm flow. If culverts are not properly sized for site-specific factors, culvert blowouts and overtopping can occur. Improper culvert sizing and spacing in Breitenbush, Oregon, led to severe road damage after a storm, and the estimated cost for the additional culverts that would have properly drained the watershed was $23,500, or 21 percent of the estimated $110,000 that was necessary to restore the road after the storm (Copstead et al., 1998).

If possible, install arch culverts (Figure 3-4) to avoid disturbance to the stream bottom, or place culverts within the natural streambed (Figure 3-27). Place the inlet on or below the streambed to minimize flooding upstream and to facilitate fish passage. Align large culverts with the natural course and gradient of the stream unless the inlet condition can be improved and the erosion potential reduced with some channel improvement. Use energy dissipators at the downstream end of the culverts to reduce the erosion energy of emerging water.

- Design stream crossings to fail during very large storm events.

Stream crossings cannot be designed for the largest possible storm that could occur, and rarely but eventually many streams will carry flows that exceed even the largest stream crossings along it. If stream crossings are not designed to fail under such circumstances, major erosion can result. One of the most important aspects of designing a stream crossing for failure is to design the path that excessive stream flow will

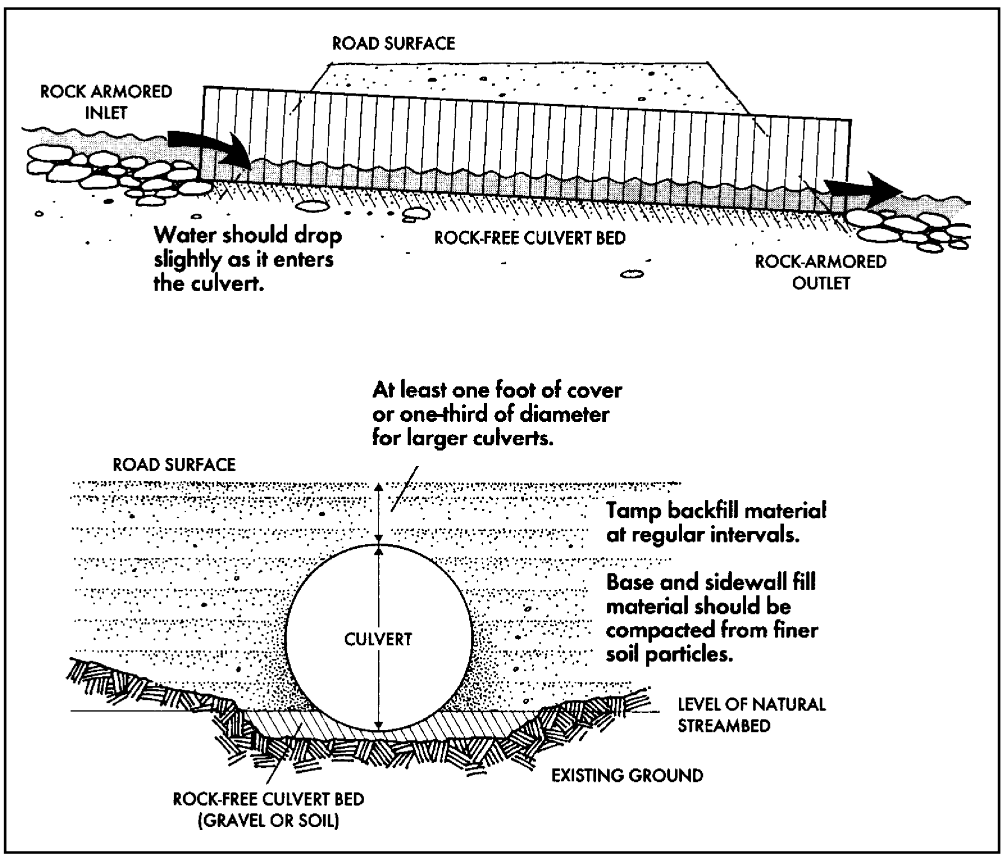

Figure 3-26. Design and installation of pipe culvert at stream crossing (Montana State University, 1991).

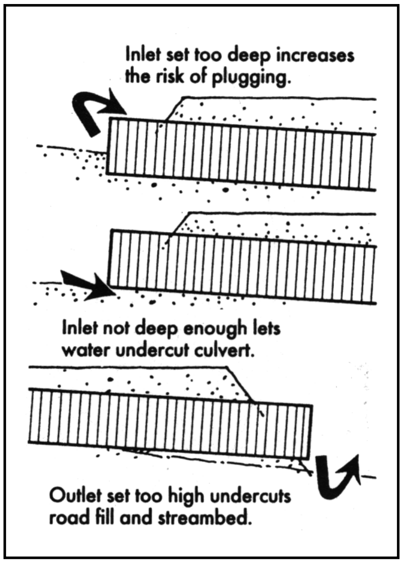

Figure 3-27. Proper installation of culvert in the stream is critical to preventing plugging or undercutting (Montana State University, 1991).

follow (Furniss et al., 1997). Maximize the likelihood that the excessive flow will follow the natural course of the stream. The following are means to achieve this objective (Furniss et al., 1998):

- Locate stream crossings where the road grade rises away from the crossing at each approach.
- Create a rolling grade where a stream is crossed on a climbing road to prevent overflow from flowing down the road.
- Design stream crossings with the least amount fill possible and construct fills with coarse material.

◆ *Construct bridges and install culverts during periods when streamflow is low.*

◆ *Do not perform excavation for a bridge or a large culvert in flowing water. Divert the water around the work site during construction with a cofferdam or stream diversion.*

Isolating the work site from the flow of water is necessary to minimize the release of soil into the watercourse and to ensure a satisfactory installation in a dry environment. Minimize environmental effects by limiting the duration of construction and by establishing limits on the quantity of surface area disturbed and the equipment to be used. Also, operate when disturbance can most easily be controlled, and use erosion and sediment controls such as silt fences and sediment catch basins. Only use diversions where constructing the stream crossing structure without diverting the stream would result in instream disturbance greater than the disturbance from diverting the stream. Figure 3-28 portrays a procedure for installing a large culvert when excavation in the channel of the stream would cause sedimentation and increase turbidity.

◆ *Protect embankments with mulch, riprap, masonry headwalls, or other retaining structures.*

Some form of reinforcement along stream banks at road stream crossings can reduce sediment loss from these sites (Table 3-19). Soft protection, such as mulch or forest debris, or hard protection, such as gravel or riprap, can be used to protect these vulnerable locations.

◆ *Construct ice bridges in streams with low flow rates, thick ice, or dry channels during winter. Ice bridges might not be appropriate on large water bodies or areas prone to high spring flows.*

Ice bridges can provide acceptable temporary access across streams during winter. Ice bridges are made by pushing and packing snow into streams and applying water to freeze the snow (Figure 3-29). Their use is limited to winter under continuous freezing conditions. A permit might be necessary before an ice bridge crossing can be built, and operators can check this with the appropriate state agency prior to ice bridge construction.

The Minnesota Extension Service (1998) suggests the following when building an ice bridge:

- Choose a period when night temperatures are below 0 °F.

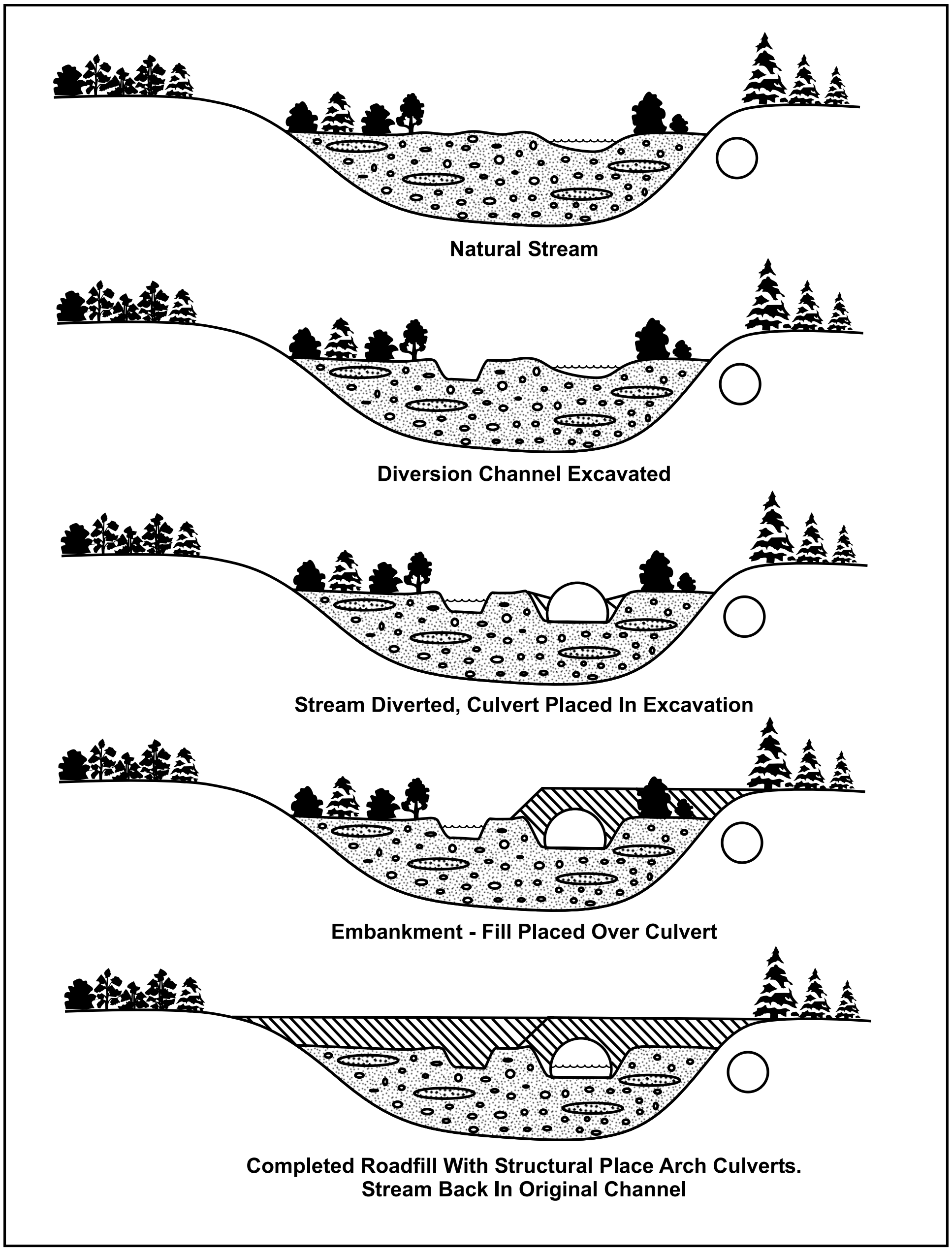

Figure 3-28. Procedure for installing culvert when excavation in channel section of stream could cause sediment movement and increase turbidity (Hynson et al., 1982).

Table 3-19. Sediment Loss Reduction from Reinforcement at Road Stream Crossings (Rothwell, 1983)

	Embankment Reinforcement with Mulch	No Reinforcement
Quantity of Sediment Lost	566 kg/day/ha	2,297 kg/day/ha

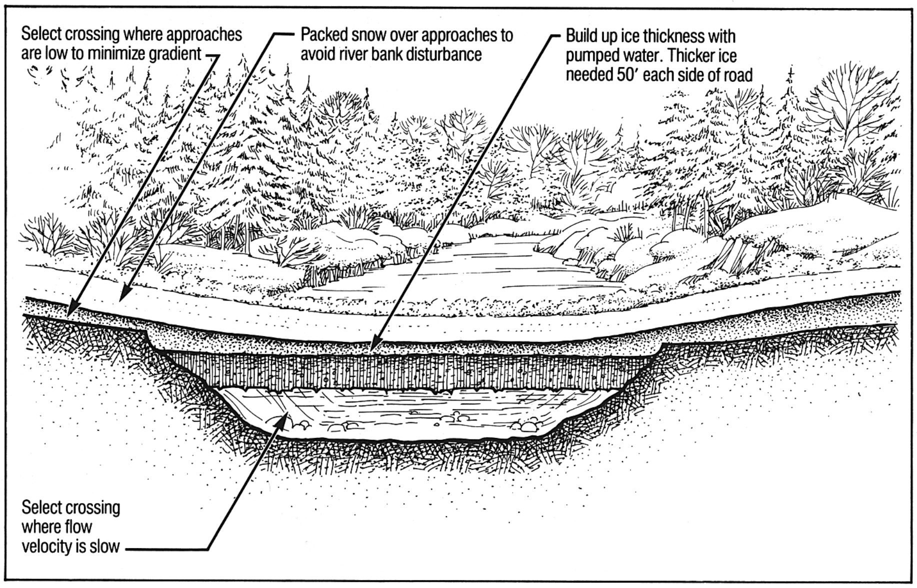

Figure 3-29. Details of ice bridge construction for temporary stream crossing in winter (Ontario MNR, 1990).

- Make the approaches to the ice bridge nearly level or level.
- Don't add brush or other vegetation to the ice bridge. Doing so weakens the structure and can create a dam when the bridge melts.
- Let the surface freeze; then repeat the construction process until the crossing is of the desired thickness and width.
- Make the bridge thick enough to permit a level approach.
- Also, make the ice thick enough to support the weight and speed of anticipated traffic.
- Inspect the bridge often, because weather and water flow can affect its strength.

Properly constructed winter roads have provisions for adequate drainage during winter weather warmups, and for the spring thaw. If a winter thaw occurs, expect to temporarily shut down road travel. The thaw creates working conditions similar to a wet weather event and causes erosion, severe soil compaction, rutting, and possibly vehicle damage.

Fish Passage Practices

◆ *On streams with spawning areas, avoid construction during egg incubation periods.*

◆ *Design and construct stream crossings for fish passage according to site-specific information on stream characteristics and the fish populations in the stream where the passage is to be installed.*

The types of structures recommended for use on forest roads as fish passage structures are listed below in order of preference (WADOE, 1999). The choice and design of each is determined by a number of factors, including sensitivity of the site to critical fish habitats, engineering specifications, cost, and availability of materials.

1. Bridges—permanent, semipermanent, and temporary
2. Bottomless culverts or log culverts
3. Embedded metal culverts
4. Nonembedded culverts
5. Baffled culverts

Baffled culverts are the most complicated type of fish passage and are the most difficult to design and construct.

To ensure safe fish passage can be provided without resulting in unacceptable effects on existing fisheries habitat values, consider physical, hydrological, and biological factors to determine whether a structure is acceptable for a site. Review the harvest plan and, based on actual site conditions, make any changes necessary to ensure adequate fish passage. Streamflow, bottom substrate, approach slopes, and soil types on either side of the stream are some details from the harvest plan to verified at the site prior to constructing stream crossings and installing culverts. The minimum site data for any proposed bridge or major culvert include

- Cross section showing the high water mark and profile of water crossing.
- Description of water body bed materials.
- Presence or absence of and depth to bedrock.
- Water velocity and direction.
- Bankfull width and depth.
- Bottom channel width.
- Channel topography, including gradient for the site and reach.
- Assessment of natural sediment and debris loading and any other condition that might influence the choice, design, and location of a structure.
- Existing improvements and resource values that might influence the structure.

Minimum biological data for successful stream crossing design include

- Species of fish that you'll want to safely pass
- Size of fish that will pass (life stage)
- Time of year in which fish passage occurs
- High and low design passage flows

The success of any fish passage structure depends very much on channel adjustments that occur after construction of the stream crossing, so it is important to survey far enough upstream and downstream to account for any possible channel conditions that might affect the design and placement of the structure.