Colorado Forest Road Field Handbook

Photo: R.M. Edwards


Photo: Colorado State Forest Service

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Photo: Colorado State Forest Service

Introduction

This handbook discusses the major aspects of forest roads management as it relates to their design, location, inspection, maintenance and repair. Most private and state forest roads are already in existence, thus the primary focus of this publication is to assist landowners in the management of these in-place roads. All photos, unless otherwise noted, are courtesy of the Oregon State University Extension Service.

Importance of Forest Roads

Why should we care about our forest roads? Consider them in terms of:

- **Capital Investment**

  Forest owners may have as little as $1,000 or upwards of $100,000+ per mile invested in their road systems. Proper design and location of roads will reduce the need for major repairs and save on maintenance costs over time. The ability to prevent damage to roads and structures by developing a routine inspection, maintenance and repair regime can reduce the amount of money invested in roads.

- **Management Access**

  A well-constructed and maintained forest road enables owners' access to their properties for harvesting operations, reforestation projects, timber-stand improvement activities, fire protection and suppression, recreation opportunities and search and rescue.

Photo: Paul Cada

- **Operational Features**

The basic requirements of a planned and functional forest road should meet the needs of the landowner for the intended use with a properly designed grade (+/-) and curve alignment. Based on the planned use, the basic requirements of a planned and functional road should have adequate width and clearance, stable surfacing and, regardless of surface type, the ability to drain and dispense water.

- **Return on Investment**

An all-season road system will allow forest owners to extend the operating season for harvesting activities. Historically, this often has resulted in the ability of operators to capture better log markets during the "off-season" winter/early spring months. A growing interest and potential for fee operations involving recreation and fishing and hunting activities during wet weather is made possible by an all-season, durable aggregate or gravel surface road system.

- **Environmental Issues and Regulation**

There is a connection between forest roads, the quality of aquatic habitat and fish. The direct physical alteration of streams from road construction and repairs can affect fish passage. The indirect physical alteration of these activities also can affect aquatic habitat. Properly designed roads and water course crossings will protect aquatic habitat from sediment and impurities that may reach streams and lakes.

- **Land Stewardship**

Sound land stewardship and the sustainability of our forests are important to private landowners and society as a whole. Applying forestry best management practices to manage for protection of water quality and habitat on private forests has positive social, environmental and economic benefits.

Road Access

Regardless of the intended purpose, roads are not useful if forest owners do not have legal access to them. Access may involve obtaining the right to use another forest owner's roads or granting ingress/egress across one's own property. It is important to remember that the use of any forest road requires a consistent inspection, maintenance and repair regime. Sources for additional information on easements and contracts can be found in the "Assistance" section of this handbook.

The four primary methods of gaining road access include:

- Permanent Easement
- Non-permanent (License) Agreement
- Reciprocal Agreement
- "Gentlemen's Agreement"

Permanent easements contain a certain number of common elements, including:

- permanent/long-term use of roads;
- name of grantor/grantee;
- legal description of the road;
- exclusive/non-exclusive use;
- stipulations for use;
- reservation of natural resources; and
- cost.

Non-permanent or license agreements are similar to permanent easements. The primary differences are related to cost, duration and insurance coverage. The cost of a license agreement usually contains a road maintenance fee. This fee can come in the form of a direct cash payment or maintenance on the road. If entering into a license agreement, it may be advantageous to accept full or partial payment in the form of road maintenance rather than cash, depending on circumstances. One should consider the benefits of either method before making a final determination. Once a monetary transaction has taken place, funds oftentimes will be expended on items other than forest road maintenance and repair. Common elements included in a license agreement include:

- road-use agreement,
- name of licenser/licensee,
- stated time of duration,
- legal description,
- stipulations for use,
- documentation of road condition prior to agreement,
- insurance/performance bond,
- waiver of legal responsibilities, and
- cost.

Reciprocal agreements are similar to permanent easements where parties "reciprocate" an agreement to exchange easements. Elements of these agreements include:

- easement exchange,
- perpetual, non-exclusive access,
- binding for future parties,
- stipulations for use similar to permanent easement, and
- cost (generally, one easement for the other).

A **"gentlemen's agreement"** can be a legally binding agreement. Elements of a gentlemen's agreement are basically the same as that of a license agreement. The most important thing to remember about this type of agreement is that if this method of gaining access has continued for a number of years, the party gaining access may have a legal right to use the road even if the other party has decided to end the agreement. The term "sitting on your rights" means the owner has allowed access for a long enough period of time that the other individual or company now can hold them legally responsible and continue to allow access. This process is called a prescriptive easement. In Colorado, this type of easement is acquired by open and notorious, continuous and adverse use of the land for at least 18 years. Anyone involved in this type of agreement may want to seek legal counsel. Gentlemen's agreements are:

- informal,
- substitute for license agreement,
- include stipulations for use,
- generally are not legally binding, and
- have implied restrictions (ambiguous, details may not be accurately recalled).

Note: Cost for easements are highly variable and generally are paid at a set dollar amount per truckload of logs and/or maintenance and repair of the road in use.

Contracts

In today's highly litigious society, the importance of a written contract cannot be overemphasized, whether negotiating an easement, constructing a road or engaging in any other forestry operation. Regardless of the operation, it is imperative that forest owners develop a contract stipulating performance requirements.

What is a contract? In its most simple form, a contract:

- is a promise between two parties;
- serves as a binding legal document;
- specifies who is responsible for doing what, when, how and for whom; and
- is a concise document that can allow for modifications or amendments.

A contract can define goals and objectives of the activity and serve as a means to achieve those goals and objectives while protecting the interests of the parties involved. Contracts can limit legal liability with insurance, limitations, exclusions, etc. and serve as a basis to recover damages if performance obligations are not met. When retaining an attorney prior to entering into a contract with an individual or company, one should request references and recommendations from previous clients and enquire about the specific level of experience regarding desired tasks.

All written contracts should contain the names, addresses and signatures of the parties involved, including:

- landowner,
- operator/contractor,
- subcontractor, and
- third-party interests, administration or representative

They also should include a clear, concise description of the work to be done, sometimes called a "scope of work," which consists of:

- the location of the work to be done;
- exhibits such as maps with legal descriptions;
- provisions for modifications;
- payment for work completed to specifications;
- standards of performance;
- start and end dates;
- work schedule;
- payment schedule and method;
- in-stream work, permits and techniques; and
- provisions for wet-weather operations.

Other requirements may include:

- provisions for extensions, adjustments, termination, etc.;
- access fees, maintenance and easements;
- equipment requirements;
- fire protection/compliance;
- permits, written plans and prior approvals;

- provisions for substandard or incomplete work;
- assignment of contract (subcontracting);
- ownership of timber and/or other salvage;
- collateral damage (both personal and property damage);
- bonding requirements; and
- insurance requirements, including:
  - commercial general liability,
  - broad-form property damage coverage endorsement, and
  - compliance with requirements of Colorado workers' compensation laws.

Specific issues need to be considered if landowners decide to contract their road construction and/or maintenance. A forest roads contract also should include:

- type of road to be constructed (i.e. a ditched road or an outsloped road without a ditch);
- initial clearing of the road corridor and methods and disposition of logs and vegetative debris;
- location and stabilization of excavated material;
- type and method of road subgrade and surface finishing (tied to the intended season of use);
- type, grade, and placement of drainage structures such as ditches and relief culverts;
- stream-crossing and road-drainage structures for fish passage, if required;
- road location (either direct or survey and office design), including standards for minimum/maximum grades and minimum/maximum curve radius and curve lengths;
- road maintenance during logging operations (including erosion and access control); and
- final road maintenance after logging.

Photo: Paul Cada

Colorado Forestry Best Management Practices (Colorado State Forest Service [CSFS], 2010)

"Forestry Best Management Practices to Protect Water Quality in Colorado 2010" was recently published by the CSFS. This document was condensed from the 1998 CSFS publication, "Colorado Forest Stewardship Guidelines to Protect Water Quality: Best Management Practices (BMPs) for Colorado". In addition, recommendations from a 2008 BMP field audit report (CSFS, 2008) are also incorporated. Best Management Practices can further be described as:

- originating from the federal Clean Water Act of 1972 legislation;
- being referred to as "BMPs";
- generally defined as "a practice or usually a combination of practices that are determined by a state or a designated planning agency to be the most effective and practicable means (including technological, economic and institutional considerations) of controlling point and nonpoint source pollution at levels compatible with environmental quality goals." (Helms, 1998);

Photo: Big R Bridge

- forestry BMPs endeavor to control nonpoint sources of pollution and are water-quality driven;
- voluntary practices on private land;
- being required by many private, third-party forest certification programs (e.g. the American Tree Farm System and the Sustainable Forestry Initiative or SFI) in order to maintain status as participant (Ice, et al., 2010);
- recent Colorado BMP audit report shows an 87-percent application rate and a 91-percent effectiveness rate (CSFS, 2008); and
- applying to all forest management activities, including forest health treatments, fuels mitigation projects and product harvests.

Roads can "produce up to 90 percent of sediment from forest activities" (CSFS, 2010), therefore, it is recommended that forest owners:

- plan for and properly design and locate roads;
- utilize minimum road design standards for the anticipated use and type of equipment;
- control erosion and stabilize slopes during the road construction process;
- manage drainage from the road surface and minimize disruption of natural drainage patterns;
- periodically maintain the road system; and
- close and/or decommission unneeded roads.

Road Surface

Road Section Types and Nomenclature

Four general types of road sections are used to construct roads over various terrain classes. They are cut-and-fill, full-bench, through-cut and through-fill (Figure 1-1).

The most common road section type is the cut-and-fill section and is used on cross-section slopes up to 45-55 percent (depending on soil type). After this upper limit of 45-55 percent, full-bench sections generally are used. Through-cuts are used to avoid excessively steep road grades and require ground to be cut. Through-fills are used to cross drainage areas, flat terrain and wetlands where water often is found.

Figure 1-2 illustrates general road element nomenclature. Although this specific example shows a cross-section of a cut-and-fill road, the elements apply to most road types.

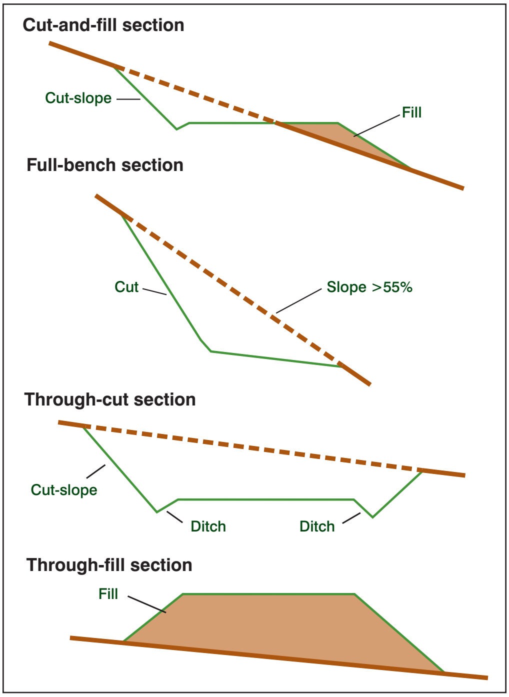


Figure 1-1. Types of road sections.
Source: Brian Kramer

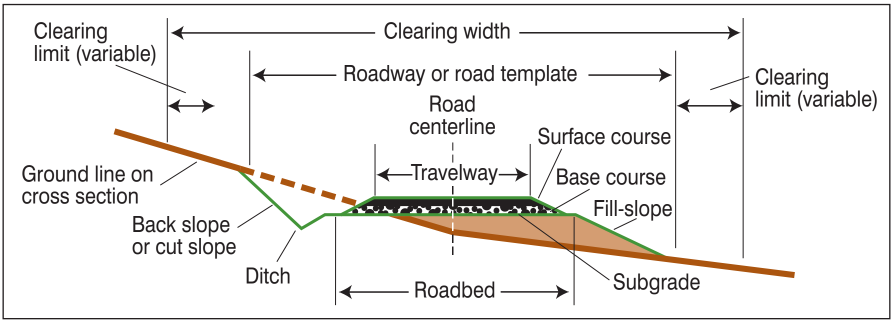


Figure 1-2. Road element nomenclature. *Source: Brian Kramer*

Road Shape

The vast majority of forest roads in use are roads that existed before the current owner purchased or actively managed the property. If planning new road construction or relocating existing roads, consult the "Road Location" section of this handbook for additional sources of information.

The different geometric road shapes include:

- crowned,
- insloped,
- outsloped, and
- no-shape.

A road surface should shed surface runoff water. The geometric shapes of the three basic types of forest road surfaces that will allow this to occur include crowned, insloped and outsloped roads (see Figure 1-4). The crowned road surface carries surface runoff to both sides of the road. Insloped roads carry water to the interior (or uphill side) of the roadway and, like crowned surfaces, use rolling dips to channel water under the roadbed and remove runoff to the downhill side of the road. Outsloped roads shed runoff to the downslope side of the road and generally do not have a ditch on the uphill side.

Currently, ditched roads are the most common, though if the application is done correctly, outsloped roads can lower the cost of construction and maintenance. However, outsloped roads generally are not appropriate for roads that are used during the winter. Outsloped roads can be hazardous to use during snow-covered, icy or wet conditions. All road shapes can be surfaced with aggregate or native non-organic materials, depending on specific road-use requirements, such as the season use will occur.

Wet-season operations generally require an all-weather, durable aggregate or native gravel surface. Both ditched and outsloped roads have common elements; the only exception is how to accomplish roadway surface drainage.

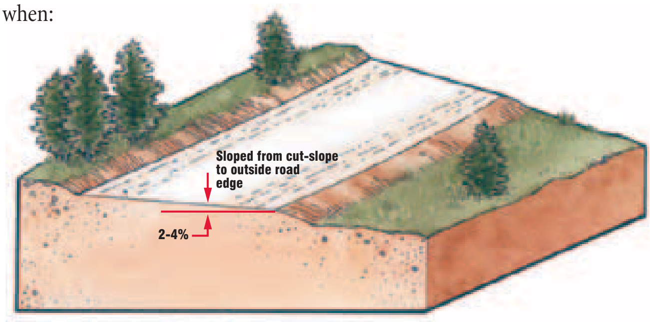
Another road shape encountered on private forests is roads with no distinct surface geometry (i.e. "no-shape," as in Figure 1-3). These roads do not effectively shed surface runoff water and require different water diversion techniques and maintenance routines than roads with a specific surface geometry.

Figure 1-3. Example of a no-shape road.

Outsloped Road

Outsloped road is used when:

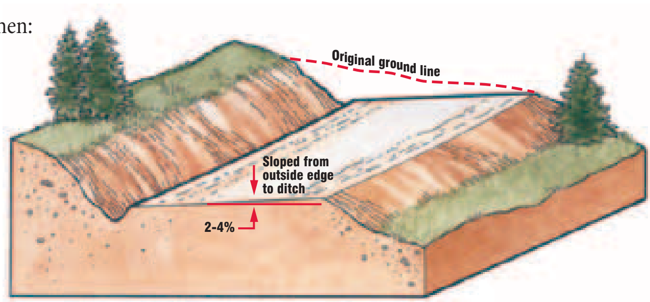
- Road grade is gentle or flat (< 8%)
- Ditch or cut-slope is unstable
- Surface can be kept smooth
- Road is vacated
- Rutting can be controlled
- Road use is seasonal and traffic is light



Insloped Road

Insloped road is used when:

- Road grade is steep (>8%)
- Surface drainage is carried to a ditch or surface drain
- Outslope causes fill erosion
- Outslope is ineffective due to ruts
- Slippery or icy road conditions are prevalent



Crowned Road

Crowned road is used when:

- Two traffic lanes are needed
- Single lane road on steep grade
- Regular maintenance of ditches, crown and cross drains is possible
- Slippery or icy road conditions are prevalent
- Road grade is flat (crown fill)

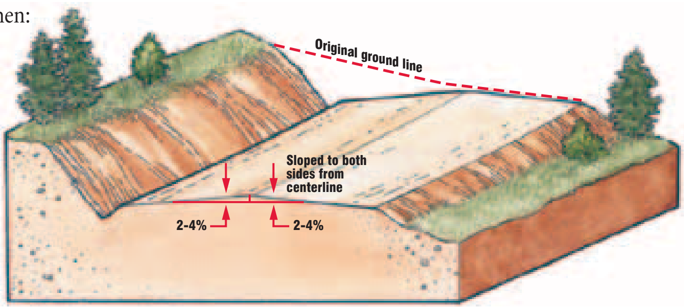


Figure 1-4. Road surface geometries.

Some of the positive attributes of outsloped roads include:

- no road ditch,
- narrower road,
- shorter cut-slope,
- less soil excavation,
- no concentrated drainage, if constructed and properly maintained, and
- works effectively for paved roads.

Following are some of the potential problems associated with outsloped roads:

- Outsloped roads don't work well for steep road grades.
- The surface shape must be rigorously maintained to preserve drainage function.
- Cut-slope failures can contaminate aggregate surface.
- Sediment delivery to adjacent and parallel streams may increase.
- Fill-slope failures occur if water concentrates due to rutting and/or poor grading.
- Outsloped roads are not appropriate for areas where use may occur during periods of snow and ice.

Figure 1-5. Example of an outsloped road.
Photo: Kelly Rogers

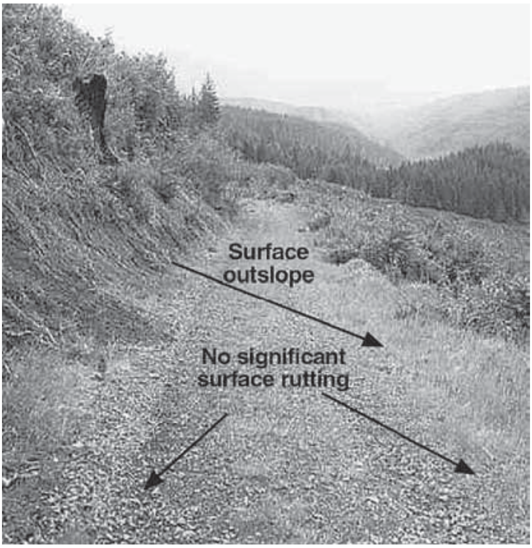


Figure 1-6. Outsloped road with minor cut-bank sloughing after above average rain storm event.

Cut-and-Fill Slopes

Regardless of the surface shape, a certain amount of excavation (cut and fill) is required to construct these roads. Cut-and-fill slope angles on a road are expressed as a ratio of the horizontal distance to the vertical distance of the slope with the vertical distance fixed as "1." Road cuts and fill banks should be constructed to slope angles that minimize slope failure and raveling.

For example, as shown in Figure 1-7, if the roadway cut-slope is expressed as the ratio 1.5:1; then the slope is on an angle with a horizontal distance of 1.5 feet and a vertical distance of 1 foot (or 34 degrees). Table 1-1 illustrates some common slope ratios for different soil/rock conditions. Table 1-2 lists cut-and-fill slope ratios and their corresponding percent slope and degree slope equivalents.

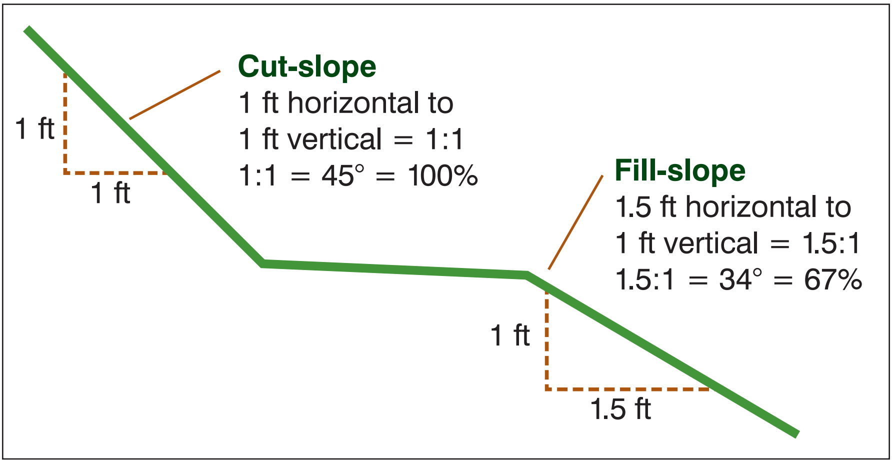


Figure 1-7. Cut-and-fill slope ratios. *Source: Brian Kramer*

Table 1-1. Common Stable Slope Ratios for Varying Soil and Rock Conditions.
Source: Kellar and Sherar, 2003

Soil/Rock Condition	Slope Ratios (Horizontal:Vertical)
Most rock	¼:1 to ½:1
Most in-place soils	¾:1 to 2:1
Very fractured rock	1:1 to 1 ½:1
Loose coarse granular soils	1 ½:1 to 3:1
Heavy clay soils	2:1 to 3:1
Soft clay-rich zones or wet seepage areas	2:1 to 3:1
Fill of most soils	1 ½:1 to 3:1
Fill of hard angular rock	1 1/3:1 to 1.5:1
Low cuts and fills (<6-10 ft high)	2:1 or flatter (for re-vegetation)

Table 1-2. Cut-and-Fill Slope Ratios with Percent and Degree Slope Equivalents.

Cut-and-Fill Slope Ratio	Percent Slope	Degree Slope
3:1	33	18
2:1	50	27
1½:1	67	34
1:1	100	45
¾:1	133	53
2/3:1	150	56
1/2:1	200	63
1/3:1	300	72
¼:1	400	76
Vertical (rock cliff)	Undefined	90

Several factors need to be considered with cut-and-fill slopes:

- In steep terrain, cut-slope raveling and slides are common if soils are deep or the rock is fractured and loose.
- Sidecast on steep slopes can begin to fail quickly or several years after initial construction. Signs of failure are arc-shaped cracks along the outside edge of the road.
- Debris collects in ditches, and vegetation may block water flow; however, light vegetation can stabilize ditch banks.
- Ditch inspection should occur prior to storm events and "problem areas" should be visited during storms when problems are most obvious.
- Displaced soil and debris should be moved to a location where they will not create additional erosion problems.
- Be aware that these problems may indicate the need for larger ditches, more culverts or armoring with rock.
- Seed and mulch bare cut-and-fill slopes to reduce erosion.
- Clear standing trees a few feet back from the top of the cut-slope to prevent potential falling.

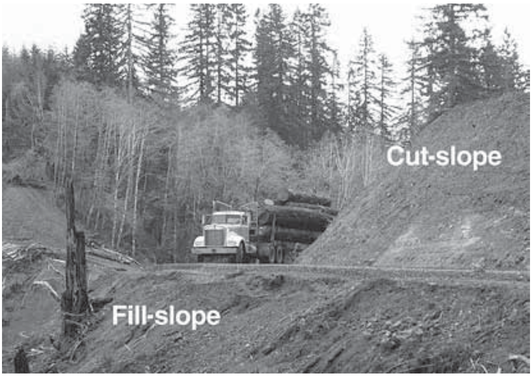


Figure 1-8. Cut-and-fill slope example.
Photo: Brian Kramer

In the simplest terms, forest road surfaces are either unimproved (native surface) or improved (aggregate or gravel surface that has been brought in).

The basic features of unimproved roads include:

- "original" soil,
- less expensive,
- higher maintenance,
- access only during the dry season,
- "in-road" water diversion structures required, and
- higher erosion and potential for sedimentation.

During the winter, or when an unimproved road is not being actively used, it should be completely waterbarred or blocked for use. (See Figure 1-9.)

The basic features of improved roads are as follows:

- requires hauling,
- initial expense is higher,
- maintenance requirements are lower if done correctly,
- erosion and sedimentation potential is lower,
- year-round access, and
- oftentimes no water bars exist.

Figure 1-9. A soil trench barring entrance on unimproved road surface.

Figure 1-10. Improved road surface with off-site aggregates.

Soil Categories and Groups

Soil makes up the subgrade (or foundation) of every road. Each soil category possesses certain engineering performance characteristics, based on particle size, as a road subgrade material. These categories are combined in differing percentage mixtures to define a soil group or subgroup. A discussion of soil groups and subgroups in relation to engineering properties is beyond the scope of this guide. Table 1-3 illustrates five main particle size categories from largest to smallest.

Table 1-3. Particle Size Range of Soil Categories. *Source: Kramer, 2001*

Soil Category	Particle Size Range
Gravel	> 0.9 inches (cobbles, stones, and boulders)
Sand	0.003 – 0.9 inches
Silt	0.002 – 0.003 inches
Clay	< 0.002 inches
Organic Matter	Variable

Organic matter generally occurs on the top of the soil profile. This material should be removed and should not be used as a road fill material. Organic matter contributes little to the road's subgrade strength and will continue to decompose causing future maintenance issues.

In general, soil groups with high percentages of silt and/or clay do not make adequate roads; however, soil mixed with the proper proportion of silt and/or clay can provide for a cohesive, durable road surface. Percentages in each category, general cohesiveness and the amount of moisture in the soil will determine the overall suitability of the available soil as a subgrade for a forest road. This also will dictate whether aggregate or gravel surfacing or other alternative treatments such as geotextiles may be required.

Figure 1-11. *Photo: R.M. Edwards*

Aggregate and Gravel Types

Aggregate and gravel surfaces consist of old or durable rock. Old rock is used for pit run, has been on the road a long time and consists of muddy rock or sandstone surfacing. **Durable rock** is clean, hard rock without many fine-grained materials (i.e. fines) and of sufficient depth to withstand all wet-season traffic.

Aggregate comes in many sizes and qualities. Forest roads require rock with jagged, angular surfaces originating from quarries, not the smoother, rounded surface rock originating from streams and rivers. Costs are comparable between "quarry" rock and "river" rock and if given a choice, rock originating from quarries better suits the needs of forest owners.

The shape, durability and wearability of the aggregate affect the quality of forest roads:

Shape. The aggregate should be angular but not sharp enough to puncture vehicle tires. Angular aggregate particles are locked together when compacted, adding strength to the road surface. River gravel, as opposed to mechanically crushed gravel, often is too rounded to adequately compact.

Durability. The aggregate should be durable enough to resist fracturing under repeated loads. Aggregate that fractures under a load will break down and reduce the strength of the surface.

Wearability. The edges of aggregate particles should not easily wear or round off; this reduces the bonding action of angular particles and reduces road surface strength.

Hardness. The rock must be hard enough to withstand vehicle tire pressure without fracturing.

Figure 1-12. Example of angular, clean and durable rock.

Subgrade

Because subgrade material can vary in strength, the need for an aggregate or gravel surface can vary. All-weather, aggregate-surfaced roads can be constructed with varying sizes and depths of aggregate surfacing. A single layer or multiple layers of surfacing are used depending on the strength of the subgrade. Table 1-4 suggests the following aggregate depths:

Table 1-4. Required Depth of Aggregate in Different Subgrades and With or Without Geotextile (Including Base, If Used). *Source: Oregon Department of Forestry, 2003*

Subgrade	Depth without geotextile	Depth with effective geotextile
Wetland	36 inches	18 inches
Wet clay or silt	24 inches	16 inches
Well drained clay or silt	14 inches	10 inches
Typical drained forest soil	10 inches	*
Rocky or full-bench	6 inches	*

** Geotextile use adds minimal value and is not recommended.*
For heavy use (more than 10 trucks per day), or for added assurance of hauling during very wet periods, add 2 inches additional aggregate.

Two main procedures are used to spread rock. The first is to use several lifts of rock of the same gradation. The second is to use a larger base rock and place a surface aggregate over the base. The advantage of the base rock is that it generally is less expensive than several lifts of smaller aggregate. The advantage of a surface consisting of the same size aggregate is ease of surface maintenance. When rutting appears on roads with base rock surfaces, the base rock can mix with the surface rock be extremely difficult to grade.

Figure 1-13. Excavator with hydraulic rock breaker.

Running Surface

The type of material (improved or unimproved) used on a road surface depends on several factors:

Season of use. Roads used during the dry season may not require aggregate or gravel surfacing. Unimproved surfaces may be adequate, depending on their quality and the season they are used. All-weather roads are used during wet and dry seasons and require aggregate or gravel surfacing.

Quality of subgrade material at the site. A stronger subgrade material requires less surfacing rock. A gravel subgrade may not require any surfacing. Some subgrade soil categories require durable rock surfacing for operations during periods of wet weather.

Quality of rock to be added. Rock quality is related to durability and strength (if struck with a hammer, the rock will not break into several pieces). The angularity, size and percent distribution of crushed particle size also is important in determining its load-bearing capacity and how well the rock aggregate "locks" into place.

Amount of vehicle traffic. Road surface wear is directly related to vehicle weight and frequency of travel. On improved and unimproved roads, this action grinds the surface soil or aggregate particles together, which wears the soil or rock. With the passing of each vehicle, surfacing is compressed and rutting occurs.

Figure 1-14. Front-end loader and dump truck at rock quarry.

Geotextiles and Their Uses

Geotextiles are synthetic, permeable fabrics used to reduce rutting, stabilize the ground and increase the load-carrying capacity of aggregate or gravel-surfaced roads. They are used to separate rock surfacing materials from subgrade soils while allowing water to pass. Geotextiles can reduce the amount of rock surfacing needed and potentially reduce road costs.

They should be given special consideration in excessively wet areas such as slumps and bogs or heavy clay soils in shaded areas and/or northern aspects. Nonwoven fabrics generally are used and recommended for most unpaved road applications. Figure 1-15 graphically illustrates the advantages of geotextiles for forest roads.

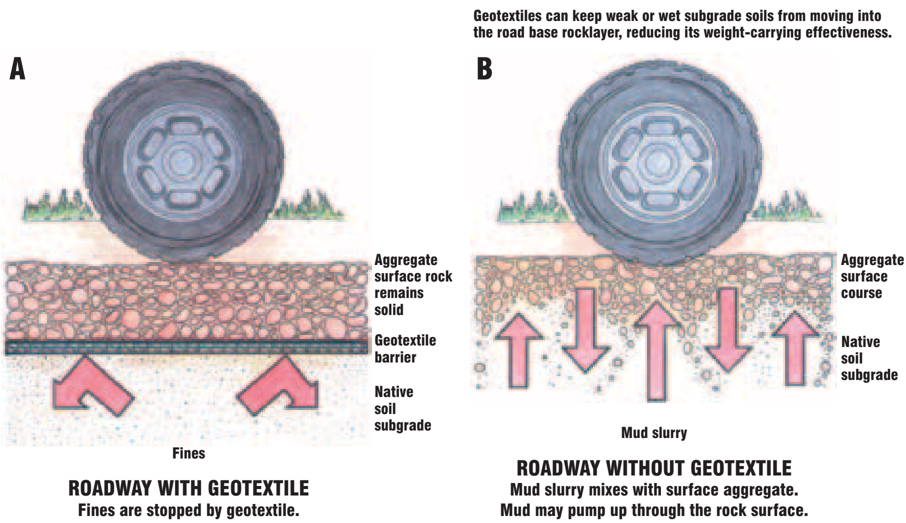


Figure 1-15. Roadways with (A) and without (B) geotextile.

Low-Usage Roads

Grass growing on the shoulders and between the ruts of a low-usage road can affect road drainage and increase the risk of wildfire during the dry season (see Figure 1-16). Many low-usage forest roads that possess these surface characteristics may cause water to bypass drainage structures, remain on the road surface, compromise the structural integrity of the road and possibly result in sedimentation issues. Normally, maintenance comes in the form of occasional rocking and permanently incorporating additional drainage structures into the road surface. Typically, landowners with these road types do not own or utilize a grader to shape their roads and the lack of disturbance to the surface allows vegetation to develop and persist.

Figure 1-16. Example of low-usage road illustrating fire hazard and vegetation issues.

Many forest owners do not invest substantial amounts of money in these low-usage roads, but they often desire a road that allows year-round access. Because of these factors, inspection, maintenance and repair regimes are different than those incorporated by commercial owners or private entities. For example, rather than rocking an entire road segment, some landowners may spot-rock and/or track-spread their rock to save time and money. If performed on a road surface that is efficiently dispersing runoff (a road with a defined geometric shape), these practices may be detrimental to effective water removal. However, if in-road structures are in place, spot-rocking and track-spreading can be successfully performed with no harmful environmental consequences such as increased erosion and/or stream sedimentation (see Figure 1-17).

Figure 1-17. Example of a low-usage road after spot-rocking and track-spreading.

Road Grade

The steepness (grade) of forest roads is classified from flat to very steep. In general terms, **road-grade classification is considered as follows:**

- A flat grade is 0 to 1 percent.
- A gentle grade is 2 to 4 percent.
- A moderate grade is 5 to 8 percent.
- Steep grades are 9 to 12 percent.
- Very steep grades are more than 12 percent.

Road grade usually is expressed as either "adverse" (+ or positive) or "favorable" (- or negative). This generally is referred to with respect to the **loaded** vehicle's direction of travel within the road system (i.e. log truck or chip van). The eye-height to eye-height method, shown in Figure 1-18, can be used to determine road grade on the ground. If a second person is unavailable, other eye-height references may be estimated from nearby vegetation or features.

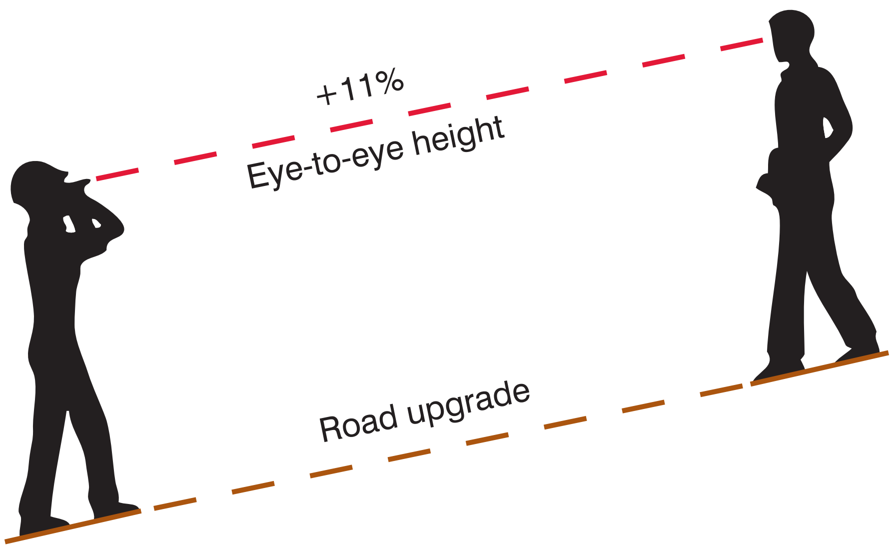


Figure 1-18. Eye-height to eye-height method of determining road grade.

Following are some general recommendations for forest roads:

- Under ideal road conditions, the minimum road and ditch grade on any road section should be + or – 2 percent to allow for adequate drainage. Road grades in the range of 2 to 8 percent are optimal.
- The maximum favorable road grade should not exceed -10 percent.
- The maximum adverse road grade should not surpass +12 percent.
- Tangential stretches of roads in switchback arrangements should not exceed +5 percent.
- The minimum horizontal curve radius should not be less than 50 feet; 60-75 feet should be used for chip vans, equipment transport (i.e. lowboys), or non-articulating emergency vehicles, depending on need.
- The minimum vertical curve should be of sufficient length so that logging trucks and equipment will not broach or bottom out.
- If applicable, locations of road intersections, turnouts and harvest landings should be approved by the operator prior to usage.
- If possible, avoid sensitive areas such as headwalls, wet areas and unstable soils.
- If applicable, a new road location should be approved by an experienced engineer or forester prior to construction.

A clinometer (Figure 1-19) is a tool used to accurately and efficiently determine road grade. These instruments are relatively inexpensive and can be used in a variety of ways.

Figure 1-19. Measuring road grade with a clinometer. *Photo: Lisa Mason*

The Road Surface: Width and Clearance

Typically, road width is not a problem, but road clearance can be a limiting factor for some forest operations requiring large equipment. A road width of 12 feet commonly is required for vehicles used in logging operations. However, many roads do not meet this requirement.

One way to minimize cost and the potential environmental impacts of forest roads is to build the road no wider than necessary to accommodate anticipated use. Table 1-5 lists road widths for several different uses.

Table 1-5. Maximum and preferred forest road running surface width (feet) for varying road uses. *Source: Bowers, 2007*

Road use	Maximum width (running surface)	Preferred width (running surface)
Minor spur and temporary	18 feet	12 feet
Collector road	22 feet	16 feet
Mainline haul roads	30 feet	24 feet

A narrower road is acceptable, but careful consideration should be given when considering horizontal curves, as shown in Figure 1-20. Off-tracking means a narrow road will need to be widened to accommodate large vehicles when negotiating curves. The minimum road surface may need to be wider than anticipated to provide truck drivers a steering safety margin. Oftentimes, a 2-foot margin on each side of the vehicle is recommended.

Vertical curves are used to make transitions between changes in the road grade from an uphill to a downhill grade, and vice versa. Vertical curves should be constructed or reconstructed with a curve length that is long enough to permit a truck to pass without bottoming out. Some forest roads have vertical clearance issues involving permanent, in-road waterbars. Before any operation involving truck traffic, roads should be carefully inspected and given consideration in terms of road width and clearance. Additional road-design considerations regarding horizontal and vertical curves and vehicle off-tracking will be discussed in the next section.

Note: Clearance requirements are substantially different for pickups versus log trucks. If in doubt, invite the operator to traverse the road and offer suggestions.

Figure 1-20. A horizontal curve with insufficient width for off-tracking with log trucks.

Road Location

Photo: Dan Wand

Road Location

Proper road location is absolutely essential to create well-designed, low-impact, and low-maintenance forest roads. Time spent properly locating a forest road will pay for itself in lower overall cost, both up front during construction and in the long run, because of lower maintenance costs. The ultimate goal is to design good roads in good locations. Properly designed roads that have adequate drainage and meet long- term resource objectives will continue to serve the landowner's long-term needs.

The location of low-standard forest roads requires specific knowledge, skills and abilities. First, practical general knowledge of road construction is needed. Essential skills include: experience in the use of aerial photos and topographic maps, clinometers, distance measuring tools (i.e. rangefinders and tapes), and hand compasses. Abilities necessary for success are detailed note-taking, basic mathematical aptitude and the stamina to work in rough terrain (Darrach, et al., 1981). If a landowner does not possess these knowledge, skills and abilities, it is best to seek assistance from your local Colorado State Forest Service district office or a forestry consultant.

Figure 2-1. Some of the field items used to locate forest roads. *Photo: R.M. Edwards*

Basically, road location control features are areas within the forest that determine the location and design of a road. They include areas that must be accessible from the road or areas that should be avoided. Figure 2-2 shows an example of a topographic road location map with control features.

Garland (2000) identifies the following as typical forest road control features:

Areas to Access:
Benches
Excavation Waste Areas
Logging Landings
Potential Stream Crossings
Saddles
Switchback locations
Areas to Avoid:
Property Lines
Rock Outcrops
Sharp Ridges and "V" Draws
Slumps and Slides
Steep Hillsides
Wet Spots, Swamps, and Springs

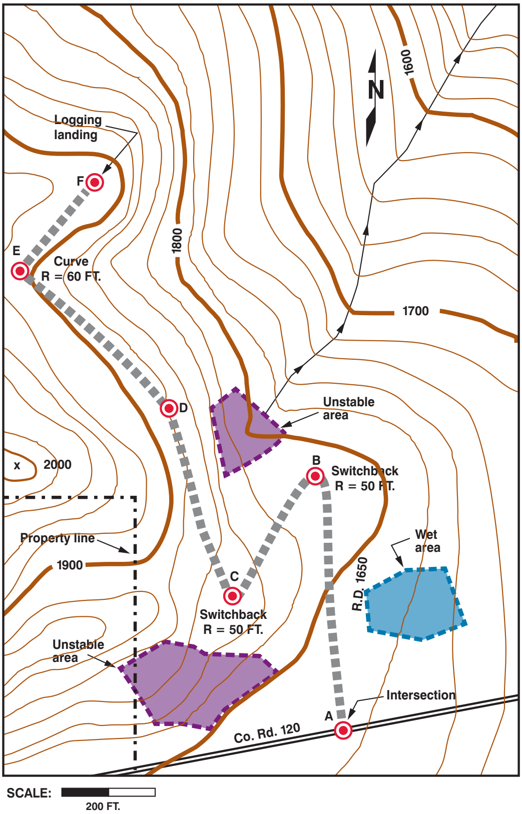


Figure 2-2. Example of a mapped forest road location using control features. *Source: Brian Kramer*

Control features should be identified on the ground and on topographic maps and/or aerial photos. US Geological Survey 7.5-minute quadrangles (quads) are widely available in paper form at most hunting and outdoor supply stores. They also are available in electronic format from various companies and entities easily found on the internet.

Similarly, aerial photos can be obtained electronically from such sources as Google Earth and other private internet subscription services. An advantage of electronic versions of aerial photos and maps is the ability to interface them with a global positioning system (GPS) handheld unit. These units allow an on-the-ground user to collect control points as "way points" and proposed "p-lines" (i.e. "preliminary" road centerlines; see below), and as "routes" or "tracks". Figure 2-3 and 2-4 represent GPS-collected data projected onto USGS 7.5-minute quads (i.e. 1:24,000 scale) and recent aerial photos.

Control features should be identified and flagged with high-visibility surveyor's tape on the ground during initial reconnaissance for a forest road location. These areas should be physically located on field maps and/or way-pointed on a GPS. The main reason for performing an intense, on-the-ground reconnaissance is to identify potential environmental problem areas and, therefore, reduce the cost of construction and future maintenance issues.

Similarly, any critical property lines nearby that may affect road design should be located before proceeding to any trial road locations. It may be necessary to engage the services of a certified land surveyor to identify property boundaries or substantiate accuracy in order to avoid illegal encroachment of any road segments onto adjacent ownerships. Time spent validating property boundary lines is time well spent.

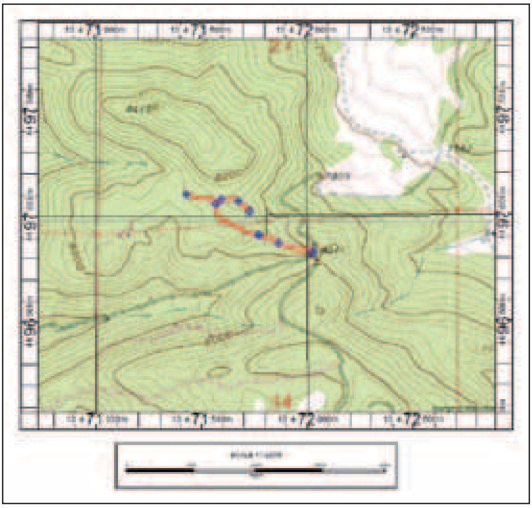


Figure 2-3. GPS-collected reconnaissance data projected onto USGS 7.5-minute quads.
Photo: MyTopo.com

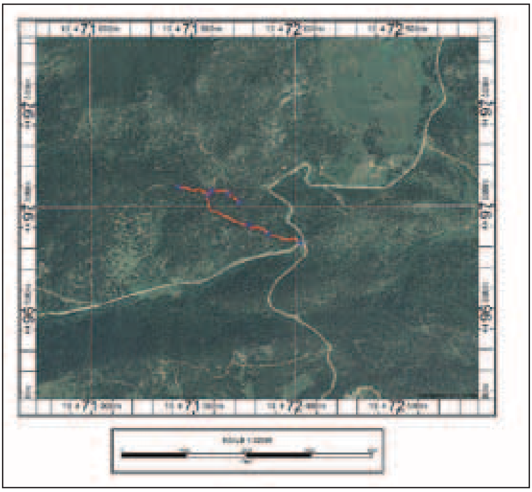


Figure 2-4. GPS-collected reconnaissance data projected onto aerial photos. *Photo: MyTopo.com*

After a satisfactory ground reconnaissance is completed and control features have been located on the ground, maps and photos, layout of the road may proceed. Following is a simplified "direct" layout/road location method suitable for cross-section slopes of up to 45 percent. This type of terrain allows for balanced cuts and fills (collectively referred to as "earthwork"), as illustrated in Figure 2-5. In turn, once the optimal road location is determined, the cut-and-fill catch points and clearing limits can be defined, located and staked, as in Figure 2-6.

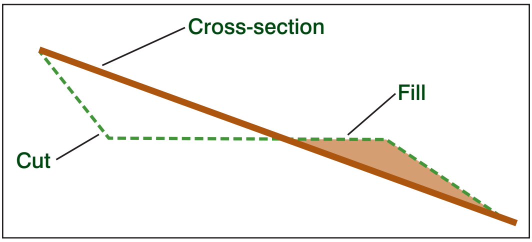


Figure 2-5. Balanced earthwork section example.
Source: Brian Kramer

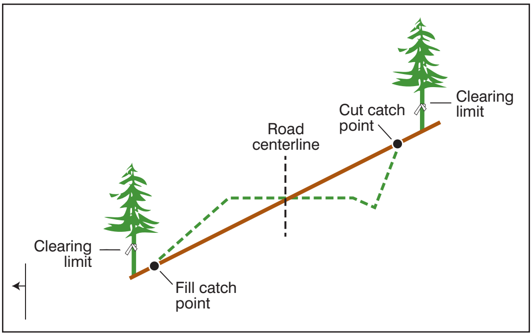


Figure 2-6. Construction survey staking a road section. *Source: Brian Kramer*

The next step is to lay out and locate preliminary grade lines, or p-lines. Lynch (2005) outlines a method for initial road layout on paper, which is the simplest method to develop a field-trial p-line. A set of draftsman's dividers and an engineer's scale are required. The method and an example follow:

- Locate the road on a topographic map using beginning and end points, controls and grade restrictions as follows:
  1) Mark the beginning and end of road and control features.
  2) Compute the elevational difference between control features.
  3) Develop a grade percent for each segment based on length and elevational difference.
  4) Set the drafting dividers at the scale difference given by the contour interval divided by the percent grade. Mark off the road by stepping from one contour line to the next with the set dividers.

  Example: (for 1:24,000 scale map)
  Divider setting = contour interval/grade as a decimal
  Given 40-foot contour interval, and 8-percent desired grade
  Divider setting = 40/0.08
  = 500 feet

In mountainous terrain, use half the divider setting and step from the starting contour line to the next mid-space, to the next contour line, to the next mid-space and repeat.

5) If the road fails to stay within the controls, re-route the segment or the whole road as needed (do the critical segments first to save time).

- Check the location of control features on the ground.
- Check grades with a clinometer in the field.
- After the best road location is determined, mark the road on the photo and map. Then, flag road route on the ground. It is usually best to start at the high point and work downhill using a clinometer to check grade.
- Final road layout should be checked by experienced foresters or engineers.

It should be noted that trial p-lines should be flagged only with high-visibility surveyor's tape as described above, preferably in a different color than control features or property boundary flagging in order to prevent confusion. Tree blazing should never be used to designate road p-lines because the location of the road may change prior to actual road construction. An alternative to flagging may be wood-survey lath stakes, especially in areas without trees and/or shrubs from which to hang flagging.

Another more involved procedure is to use a "survey and office design" method of forest road layout. This procedure requires an initial on-the-ground design using p-lines, as shown in Figure 2-8, and a ground survey of cross-sections. Finally, an office design

Figure 2-7. Mapping equipment needed for direct layout/road location. *Photo: Lisa Mason*

usually using a proprietary road design software package, and an adjusted location-line, or l-line, with slope staking as shown in Figure 2-9 would need to be performed. Full-bench section roads with large amounts of excavation material that may need to be moved large distances to balance earthwork usually fall into this category. A full-bench section road layout (i.e. slopes greater than 45 percent) should be left to professionals who have adequate equipment, experience and knowledge.

In summary, the goal is to get from the beginning to end of your road project in the most environmental and cost-efficient manner possible, which requires attention to fitting the desired road design elements to existing ground conditions, slope and topography.

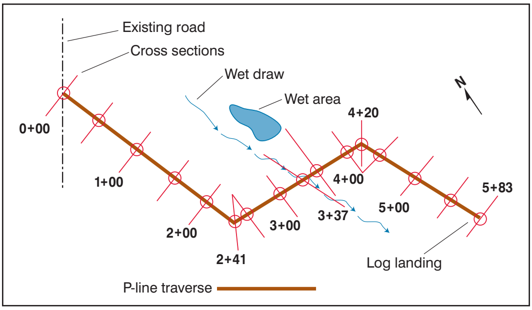


Figure 2-8. Plot of a preliminary p-line traverse survey. *Source: Brian Kramer*

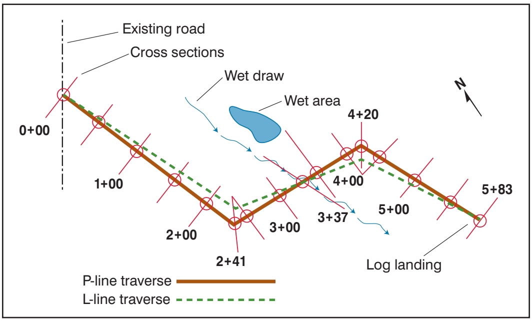


Figure 2-9. Plot of a location l-line design. *Source: Brian Kramer*

Figure 2-10. *Photo: Paul Cada*

Horizontal and Vertical Curves

Horizontal and vertical curves are used to change road direction and grade, respectively. Figures 2-11 and 2-12 provide an example of each type of curve.

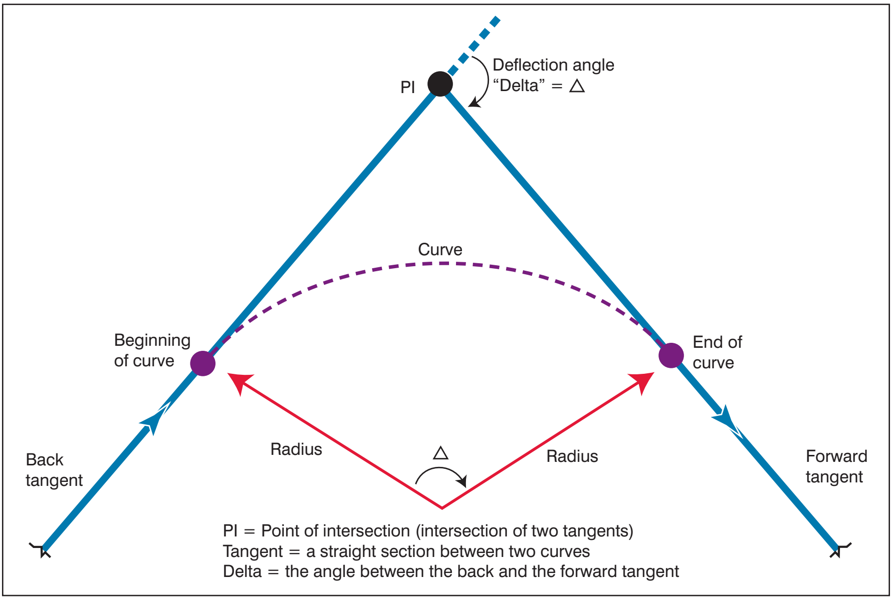


Figure 2-11. Horizontal curve description, plan view. *Source: Brian Kramer*

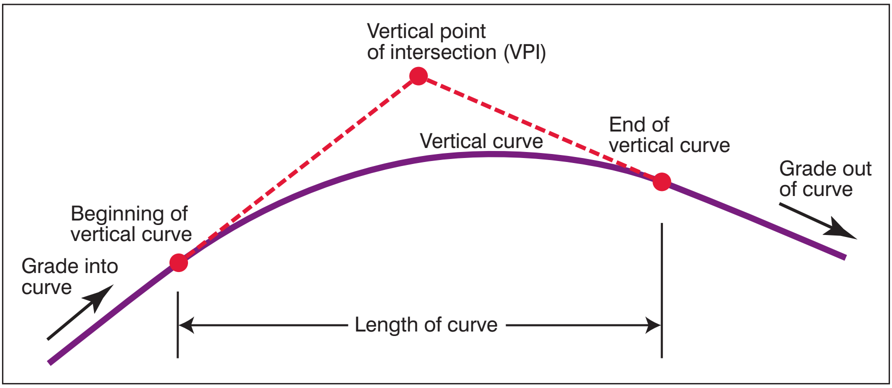


Figure 2-12. Vertical curve description, profile view. *Source: Brian Kramer*

In a forest road system, horizontal curves usually are planned with a "design" vehicle in mind. In many cases, the design vehicle will be an articulated log truck. The accepted minimum horizontal curve radius for a standard log truck is 50 feet, although some consider 60 feet a better curve radius to use. Other longer vehicles such as lengthier wheel-base chip vans, non-articulated emergency vehicles, and equipment transport "low-boy" trucks may require longer minimum curve radii up to 75 feet or longer.

Vertical curves are similarly designed. In this case, the length of the curve must be long enough to allow a truck to negotiate the curve without bottoming out on a cresting vertical curve or broaching on a sagging vertical curve (e.g. Figure 2-13). Safe sight distance and travel speed for oncoming vehicles also should be considered.

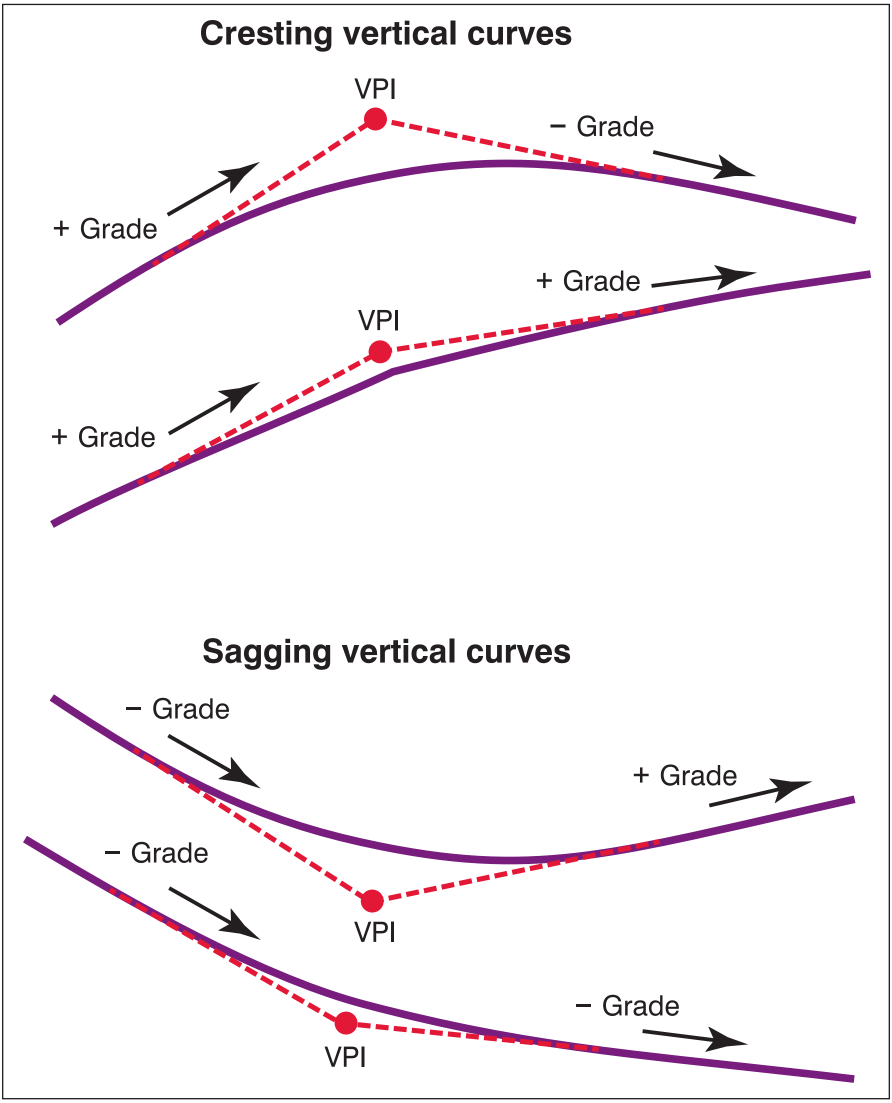


Figure 2-13. Types of vertical curves. *Source: Brian Kramer*

Curve Widening for Vehicle Off-Tracking

Figure 2-14 illustrates an articulated vehicle (e.g. chip van) off-tracking on a horizontal curve. In general, shorter radius curves require more curve widening than longer radius curves in order to account for vehicle off-tracking. Curve widening design depends on the radius of the curve, its corresponding deflection angle or "delta" (see Figure 2-11) and the type of design vehicle using the road. For example, on a 12-foot wide road surface, 8 to 20 feet of additional road surface width may be required for curve widening in order to account for off-tracking. This also assumes that adequate safe sight distance exists and low vehicle speeds are not an issue.

Table 2-1 illustrates the amount of additional road surface width required on a 12-foot road surface with a 60-foot horizontal curve radius for vehicle off-tracking. Table includes curve deflection angles varying from 30 to 160 degrees in the first column. As the deflection angle increases, the curve becomes sharper, as does the amount of curve widening.

The US Forest Service (1987) uses the guideline of a reduction in road grade of 0.04 percent per degree of curvature (i.e. deflection or delta angle). Table 2-2 shows three examples of recommended grade reductions around the given curves. Sessions, et al. (2010) also identify a need to

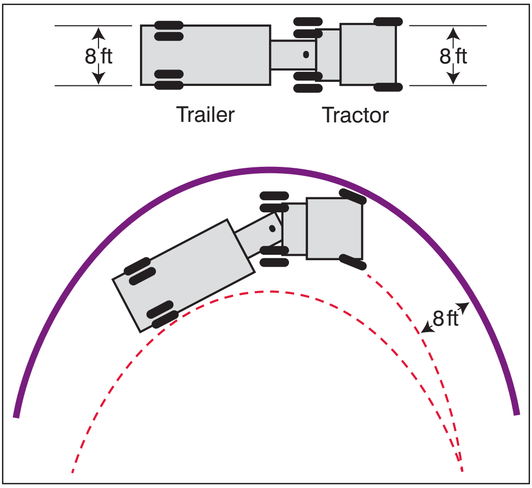


Figure 2-14. A vehicle off-tracking on a horizontal curve. *Source: Brian Kramer*

Table 2-1. Log truck and tractor-trailer off-tracking on a 60-foot radius horizontal curve, 12-foot road surface, with varying deflection angles. *Kramer, 2001*

Deflection Angle (degrees)	Log Truck Off-tracking (feet)	Tractor-trailer Off-tracking (feet)
30	2	6
40	3	8
50	3	8
60	4	9
70	4	10
80	4	11
90	4	11
100	5	12
110	5	12
120	5	13
130	5	13
140	5	14
150	5	14
160	5	14

Note: Off-tracking values are rounded to the nearest foot.

reduce the road grade on horizontal curves in order to account for loss of vehicle traction, especially for unloaded chip vans.

Table 2-2. Recommended grade reductions around horizontal curves due to low gradeability. *Source: US Forest Service, 1987*

Degree of curve	Radius of curve (feet)	Reduction (%)
50	115	2
75	76	3
115	50	4.5

Figure 2-15. Stinger-steered chip trailer negotiating curve. *Photo: Western Trailers*

Turnout Widening

Figures 2-16 and 2-17 illustrate vehicle-turnout design criteria and an actual turnout. These turnouts usually are placed in strategic locations along the road that require minimal excavation or where waste material has already been placed. If roads are being used to haul biomass or logs, the turnouts are located on the side of the road being used by incoming empty trucks, preferably in relatively flat areas. This is done so incoming vehicles can yield the right-of-way to the outgoing loaded vehicle.

Turnouts should be designed for specific vehicles. The turnout in the figure above was designed for a 20-foot wheelbase truck tractor with a piggyback trailer (i.e. an unloaded log truck). If the design vehicle has different requirements (e.g. chip vans), the turnouts need to be adjusted accordingly. In the case of a 50-foot to 60-foot van, the turnout may need to be a minimum of 100 feet with 50-foot transitions.

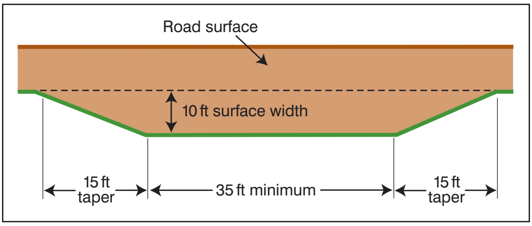


Figure 2-16. Example of a 20-foot wheelbase vehicle turnout. *Source: Brian Kramer*

Figure 2-17. Example of vehicle turnout.
Photo: R.M. Edwards

Turnaround Design

Turnarounds usually are constructed near the terminus of dead-end spur roads and landings on collector and mainline haul roads. They are installed to provide a safe and suitable area for vehicles to reverse direction and/or to back up towards landing/staging areas for loading. Generally, they are located on a fill immediately past a cut and within sight distance of the road's end on short road sections (i.e. "spurs").

Figure 2-18 illustrates details and common dimensions for a turnaround suitable for pickup trucks and piggy-back log trucks. If chip vans are being used, other options may need to be investigated. Alternatives may include the use of road intersections to back into, wide spaces on ridgetops and/or valleys, and creating turnarounds with larger dimensions, depending on the length of the vehicle's wheelbase (see example in Figure 2-18).

Road-grade control in the vicinity of chip-van turnarounds also is necessary to accommodate vehicles that need to back up towards landing/staging areas. Road gradient should be limited to 5 percent or less between the turnaround and landing/staging area, as the empty chip van will need to generate sufficient traction when starting from a complete stop. Preplanning for landing/staging areas in the case of chip vans is absolutely essential.

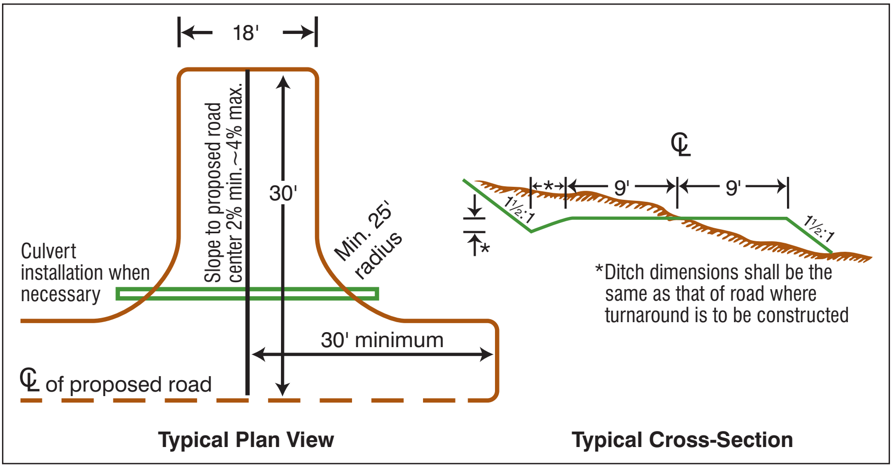


Figure 2-18. Turnaround Details. *Source: Colorado State Forest Service (After: Darrach, et al., 1981)*

If two control points cannot be connected with a straight line utilizing maximum design gradients, a switchback may be needed. As mentioned above, potential switchback locations should be identified during initial ground reconnaissance. Areas best suited for locating switchbacks are gently sloping ridge spurs or stream deltas. These areas will minimize the amount of excavation required, thus lowering the overall cost and associated resource impacts.

Figure 2-19 illustrates a switchback layout. Maximum grade (G) for the curve portion of any forest road switchback should not exceed 8 percent, and may need to be reduced based on the degree and radius (R) of the curve being installed (see Table 2-2).

In the example, grade is reduced to 0 percent prior to the beginning of curve (BOC) and after the end of curve (EOC) points. This reduction allows for a constant grade to be constructed through the switchback. If the road centerline is not located in this way, the result will be excessive gradient at the center of the switchback, which may render the road unserviceable.

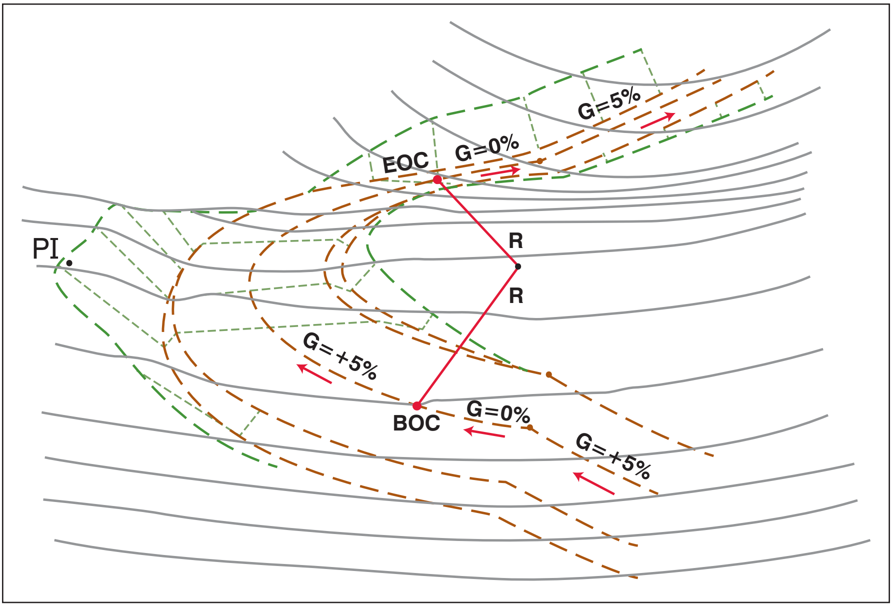


Figure 2-19. Layout of switchback to allow construction of a constant grade.
Source: Colorado State Forest Service (After: Darrach, et al., 1981)

Cross-Drainage Structures

Ditch Relief

Crowned, insloped and "no-shape" roads include a roadside ditch that collects road surface runoff and intercepted subsurface flow. Water that collects in these ditches must be diverted across or under the road onto the forest floor to avoid excessive erosion in the ditchline. Drainage relief structures vary depending on the type and quality of road constructed. These structures include:

- waterbars,
- rolling dips,
- rubber waterbars, and
- drainage culverts.

Figure 3-1. Example of a rolling dip.

The ditches of rocked, all-weather roads are drained using cross-drainage structures. Following are considerations regarding the installation and maintenance of these structures:

- **Divert** – successfully get water from the ditch into the pipe.
- **Drain** – make sure the outlet is lower than the inlet.
- **Distance** – structure spacing.
- **Dissipate** – armor the outlet from excess energy.
- **Debris** – keep the inlet clear of debris.

Figure 3-2. Example of a drainage culvert.

Following are cross-drain culvert sizing guidelines:

- When installing new ditch-relief culverts, use a minimum 18-inch diameter culvert.
- Consider using 24-inch culverts because they can be more easily accessed by a person for maintenance or repair during the dry season.
- Many 12-inch diameter culverts are currently in use. They do not need replacement, provided the structures are performing adequately, but continual inspection during the wet season is essential and additional maintenance may be required.
- These structures are not dependent on hydraulic capacity.
- Larger-diameter culverts are recommended to minimize concerns regarding plugging and inlet damage, especially if an established inspection and maintenance regime is not in place.

Figure 3-3. Steel culverts. *Photo: Big R Bridge*

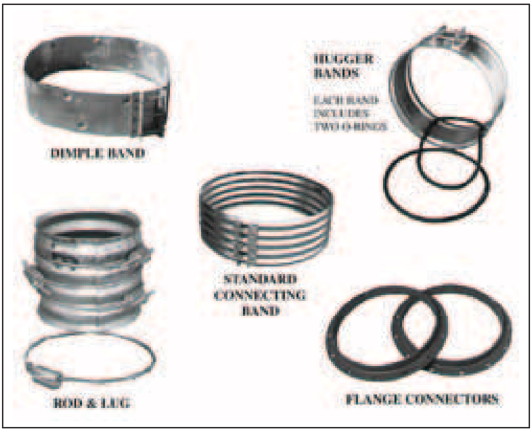


Figure 3-4. Culvert accessories. *Photo: Big R Bridge*

Culverts: Steel vs. Plastic

Plastic ditch relief culverts (shown in Figure 3-5) have grown in popularity among many private forest owners. Due to cost, plastic is used primarily in the capacity of ditch-relief culverts. The cost of 18- to 24-inch plastic culverts is comparable to steel; however, the cost increases for plastic culvert that is 30 inches and larger.

Plastic culverts are available in 20-foot sections and can easily be cut with a handsaw or chainsaw and spliced to the desirable length at the job site. Steel culverts are not as "user friendly," but do come with an assortment of product options. Some of the more popular steel culvert accessories are the half-round pipe, anti-seep collar, anchor assemblies and debris racks. There are several reasons for the growing popularity of plastic, but steel remains the preferred material for stream crossings and larger peak flows. Table 3-1 below compares the attributes of plastic and steel culverts.

Table 3-1. Comparison of plastic and steel culvert attributes. *Bowers, 2007*

Attribute	Plastic	Steel
Price	Cost is less if < or = 12-inch	Cost is less for 30-inch and larger
Ease of use	Easier than steel	Less easy
Size	Usually 36-inch and less	Available in virtually any size
Availability	Readily available	Readily available
Strength	Comparable to steel	Comparable to plastic
Durability	> 30 years	Approximately 30 years
Repairable (damaged ends)	Generally not repairable	Generally repairable
Fireproof	No	Yes

Figure 3-5. Plastic culverts.

There are recommended procedures for the installation of ditch-relief culverts. The important thing to remember is to move water from the upside to the downside of the road in the most financially-efficient and environmentally-effective methods possible. Site considerations sometimes can result in a deviation from the recommended procedure shown in Figure 3-6.

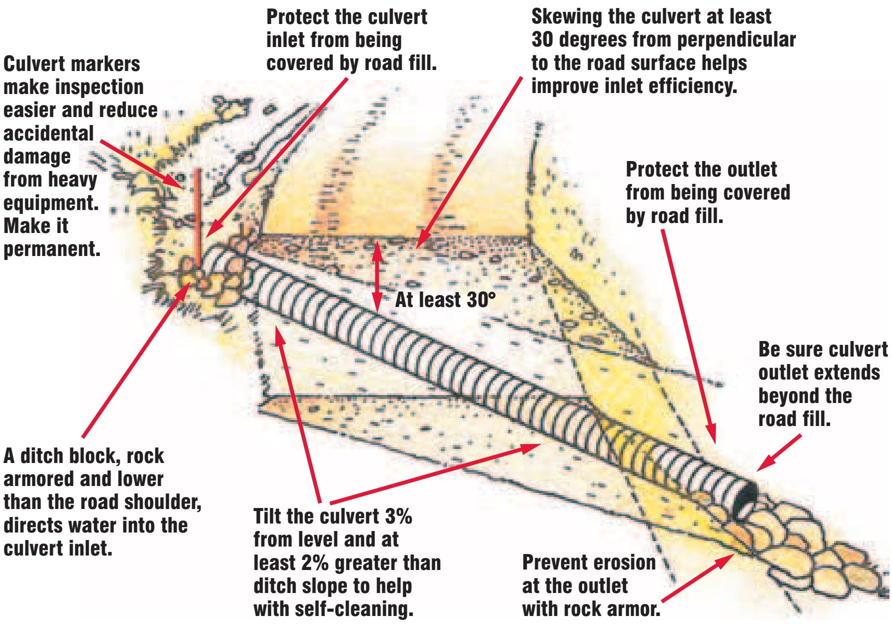


Figure 3-6. Diagram of recommended procedures for ditch-relief culvert installation.

Distance: Spacing Guidelines

Spacing for ditch-relief culverts and in-road water diversion structures (i.e. grade/rolling dips and water bars) are dissimilar in terms of distance. Soil categories, road gradient, steepness of sideslope above the road, aspect and position on slope are factors to be noted when considering spacing, depending on type of diversion structure chosen. Soil category and/or parent material classification may require the involvement of a local engineering, forestry or geotechnical consultant, or a CSFS forester (see "Assistance" section).

Tables 3-2 and 3-3 below outline the maximum spacing for both ditch-relief culverts and in-road water diversion structures, respectively.

Table 3-2. Maximum spacing (feet) of ditch-relief culverts (i.e. cross-drain structures) based on road gradient and parent material/soil category. *Zeedyck, 2006*

Road Gradient			
Soil type	**2-4%**	**5-8%**	**9-12%**
Highly erosive (granitic parent material/sand soil category)	500	300	200
Intermediate erosive (loam parent material/clay soil category)	700	500	350
Low erosive (shale parent material/gravel soil category)	900	700	500

Figure 3-7. *Photo: Colorado State Forest Service*

Table 3-3. Maximum spacing (feet) for in-road water diversion structures, specifically for water bars and drain/rolling dips at a 4-percent road gradient.

New Mexico State Forestry, 2002

	North and East Aspect									South and West Aspect								
Location of Road	Top 1/3 of Slope			Middle 1/3 of Slope			Bottom 1/3 of Slope			Top 1/3 of Slope			Middle 1/3 of Slope			Bottom 1/3 of Slope		
Parent Material*	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F	C	M	F
Steepness of Sideslope above Road (%)																		
80	145	121	95	127	103	77	109	85	59	129	105	79	111	87	61	93	69	43
70	140	116	90	122	98	72	104	80	54	124	100	74	106	82	56	88	64	38
60	135	111	85	117	93	67	99	75	49	119	95	69	105	77	51	83	59	33
50	130	106	80	112	88	62	94	70	44	114	90	64	96	72	46	78	54	28
40	125	101	75	107	83	57	89	65	39	109	85	59	91	67	41	73	49	23
30	120	96	70	102	78	52	84	60	34	104	80	54	86	62	36	68	44	18
20	115	95	65	97	73	47	79	55	29	99	75	49	81	57	31	63	39	13
10	110	86	60	92	68	42	74	50	24	94	70	44	76	52	26	58	34	8

Adjustments for Table above: *If road grade is 2 percent, add 15 feet;*
If road grade is 6 percent, subtract 8 feet;
If road grade is 8 percent, subtract 15 feet;
If road grade is 10 percent, subtract 24 feet.

***Parent Material Classification**

Course (C)	***Medium (M)***	***Fine (F)***
Hard sediments Shale (hard) Slate Argillite Rhyolite Rhyolite porphyry Limestone (hard) Basalt Basalt porphyry Quartzite Conglomerate Gravel	*Granite Sandstone Gneiss Schist Sand Glacial Silt*	*Andesite Andesite porphyry Limestone (soft) Loess Shale (soft)*

When roadside ditches cut deeper and deeper, as shown in Figure 3-8, too much water flows in the ditch. The suggested waterbar intervals may not be adequate to prevent downcutting, which may require additional cross-drain culverts. Additional structures also are recommended when no cross-drainage structures are located within a few hundred feet of a stream crossing. If it is not possible to add culverts, armoring the ditch may be the only solution. Coarse, clean rock (see Figure 3-9) usually will prevent additional erosion and may assist in filtering sediment. Rock may be used on cut-slopes and to create sediment ponds. To achieve maximum sediment retention, ditches should be 80-90 percent filled with clean rock where downcutting occurs.

Figure 3-8. Example of a roadside ditch with excessive downcutting. *Photo: R.M. Edwards*

Figure 3-9. Coarse, clean rock suitable for ditch armoring.

Dissipate

Make sure the energy at the outlet of the pipe is dissipated into rocks or slash carried below the fill with a half-round culvert (see Figure 3-10) or extended beyond the fill-slope with a flexible/plastic culvert. A strong potential for erosion exists at the outlet of these relief structures. Erosion problems may occur from exposed fill, in addition to concentrated flow at ditch-relief culverts. Slash-filtering windrows, as shown in Figure 3-11, are composed of compacted logging slash installed along the base of a fill-slope. They are very effective at slowing surface runoff and keeping sediment from entering streams.

Figure 3-10. Example of a culvert half-round dissipater.

Figure 3-11. A trackhoe compacting/installing slash-filter windrows along the base of a road fill.

Pulling (grading) a ditch with a grader or bulldozer can temporarily increase erosion. Figure 3-12 illustrates a ditch in the process of re-vegetating. It is best to pull the ditch only when it is not functioning properly. Figure 3-13 is an example of benign neglect that results in a positive outcome.

Figure 3-12. Ditch re-vegetation after disturbance.

Figure 3-13. A properly functioning vegetated ditch.

In-Road Water Diversions

Low-usage forest roads with no shape or distinct geometric road surfaces with no consistent inspection and maintenance regimes require in-road water diversion structures such as the one shown in Figure 3-14. The inconvenience of crossing these structures far outweighs the potential financial and environmental costs of a road failure.

The most common in-road water diversion is the conventional waterbar (see Figure 3-15 below). These structures are best constructed with mechanical equipment, but can be built with a shovel. If constructing waterbars with non-mechanized equipment, spacing guidelines may be insufficient for the structures to handle a significant weather event. Be sure to extend the waterbar a sufficient distance off the road surface to ensure that water does not re-enter the road at a lower point. Remember that spacing guidelines are simply recommendations. If in doubt, construct waterbars at closer intervals.

Figure 3-14. Example of an unimproved road with a waterbar.

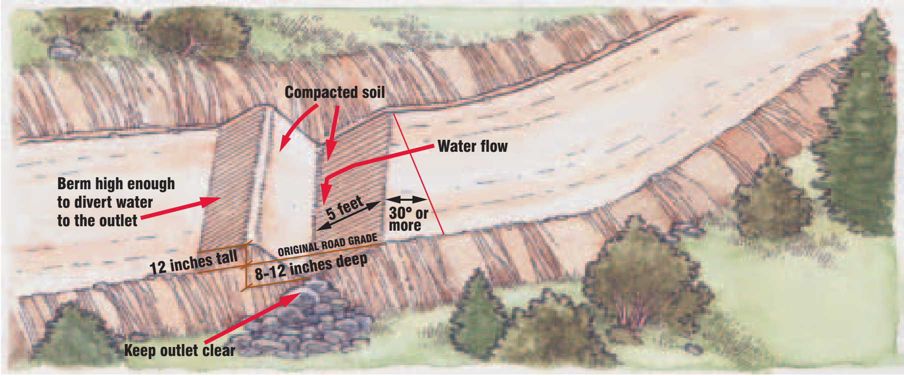


Figure 3-15. Diagram of recommended construction guidelines for a conventional waterbar in-road water diversion structure.

Drain/Rolling Dips

Waterbars on an aggregate or gravel-surfaced road are not particularly user friendly. Various methods are available that can reduce the inconvenience of crossing in-road water diversion structures. The most common method is the drain dip, or grade/rolling dip, as shown in Figures 3-16 and 3-17. Following are features of rolling dips:

- used on ditched or unditched roads;
- sloped to carry water from inside to outside the road;
- gradual depth and run-out provide drainage with easy driving access;
- effective on gentle to moderate (3-8 percent) grades; and
- ditch-relief culverts are recommended for steeper grades.

In general, rolling dips should be designed with regard to the design vehicle's height clearance and length of wheelbase. Zeedyk (2006) suggests that the total length of the rolling dip, from "runout" to "approach" grade, should equal twice the length of the longest vehicle (i.e. your design vehicle, including the trailer) that will be using the road.

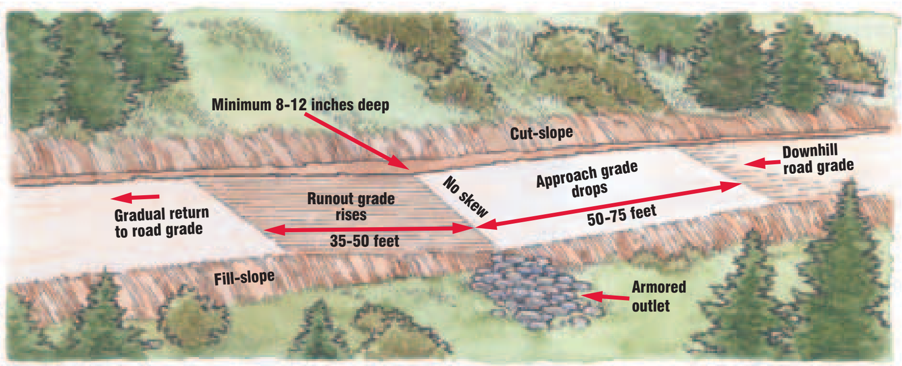


Figure 3-16. Diagram of recommended construction guidelines for a rolling dip in-road water diversion structure.

Figure 3-17. Example of a rolling dip.

Rubber Waterbars

A relatively new concept in cross-drain structures available to forest landowners is the rubber waterbar (see Figure 3-18). These structures consist of a 12-inch wide by ¾-inch thick strip of industrial rubber belting that is long enough to span the road surface. The belting is secured by lag bolts and washers to a treated 4-inch x 8-inch timber, then buried in the road surface per installation specifications in Figure 3-19. Approximately 4 inches of the belting is exposed to catch the surface runoff.

Another method of construction is to place the belting between two 2-inch x 6-inch treated boards and securing them with decking screws. Either method is acceptable, but the 2-inch x 6-inch laminated structure is somewhat easier to transport, slightly less expensive and easier to construct. Figures 3-20 through 3-22 show construction details of a laminated waterbar structure. This particular installation technique has proven to be successful.

Advantages of using rubber waterbars:

- They are extremely user friendly.
- They can be used on any slope or road surface.
- Maintenance is very low and may offset higher installation costs.
- They are easy to install.

Figure 3-18. Example of an in-place rubber waterbar.

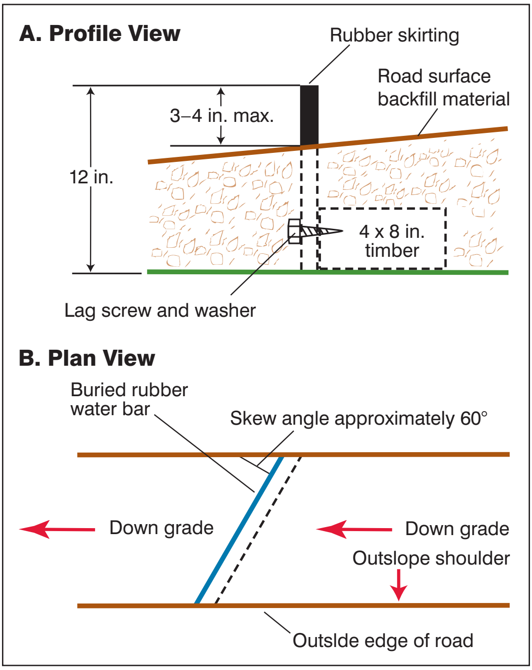


Figure 3-19. Installation specifications for rubber waterbar. *Source: Brian Kramer*

Disadvantages:

- They must be constructed because they are not available pre-assembled.
- They are relatively expensive, costing 30 to 50 percent more compared to conventional waterbars.
- Road graders cannot grade over the structures.

Depending on the situation, it may be necessary to deviate from the location and installation of any cross-drainage structure. For example, when operating steel undercarriage equipment, crossing rubber waterbars requires some type of device to protect the rubber belting, or it may need to be located where one can circumvent the structures. Providing these structures perform their intended purpose, there is no right or wrong method.

Figures 3-20 through 3-22. Construction details of a laminated 2-inch x 6-inch rubber waterbar.

Cross-Drainage on Unimproved Surfaces

In general, waterbars on unimproved roads such as the ones shown in Figures 3-23 and 3-24 are not meant to be used by log trucks, so careful consideration is essential when smaller vehicles cross these roads. Native surface soil waterbars are susceptible to erosion and, when crossed with a vehicle, can become rutted. They are sometimes dug too shallow and with an improper angle, resulting in failure. These cross-drain structures should not be accessed (i.e. temporary road closure) during the wet season and if a failure does occur, they may become susceptible to chronic erosion and sediment delivery. Waterbars should be spaced to avoid excessive erosion and have a minimum 12-inch ditch with a 12-inch berm to divert water from the ditch and road surface onto the forest floor. If a waterbar is placed in a road that is not inspected during the wet season (not recommended), the depth and frequency of these structures should be increased.

Figures 3-23 and 3-24. Bulldozer installing waterbars on unimproved surfaces.

After a timber harvest or other management activity, these roads sometimes are considered expendable. When they are again put into use, a bulldozer or rubber-tired skidder typically is used to shape the road by grading soil from the sides and/or base of the existing road. If this process displaces an excessive amount of soil, or is performed repeatedly, the surface of the road can become lower than the forest floor. Once the road becomes the lowest point in the area, it becomes impossible, or extremely difficult, to be able to divert water from the surface. Essentially, a channel has been created that is now a chronic source of erosion.

Improved and Unimproved Road Interface

Ground-based timber harvesting systems employ a combination of unimproved and improved roads. Improved surfaces serve as the mainline or primary source of access, and unimproved roads serve as skid trails, landing access and secondary roads. Forest owners should attempt to isolate each road segment and to avoid diverting water from one segment to another, thus increasing the chance for failure of the drainage structure or possibly a live-stream crossing.

If a significant amount of runoff is anticipated, it may become necessary to move water along the side of an unimproved road, away from the improved road. If possible, divert the runoff from these unimproved roads to a place where it will spread and dissipate onto the vegetated forest floor. Ditching on native surface may pose potential erosion issues because water is being transported down the side of an unimproved road and directed across the roadway using a waterbar or rolling dip. If possible, gradually angle the ditch out onto the forest floor to avoid the need to cross the unimproved road.

Figure 3-25. Example of improved and unimproved road interface.

Stream Crossings

Photo: R.M. Edwards

Stream Crossings

Many forest owners do not know what factors are used to determine what constitutes a stream. A stream has a defined bed and bank. The bed has more rocky material than the surrounding soils, and the absence or presence of water is not a defining factor in determining whether the bed and bank constitutes a stream.

It cannot be overemphasized – seek professional assistance when dealing with stream crossings!!!

This section addresses culvert sizing in terms of stream crossings and fish passage. It also addresses the various types of culverts and other possible alternatives to gaining access across a stream and determining what's best to protect fish passage. For additional information, be sure to view the "Assistance" section of this handbook.

The headwater-to-diameter ratio is the ratio of the headwater height (HW) to the diameter of the culvert (D), which should pass the design flow at a maximum HW/D ratio of 1.0. Figure 4-1 illustrates this relationship.

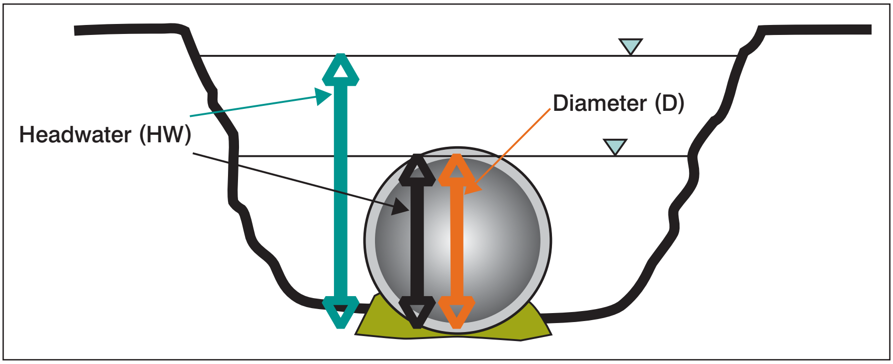


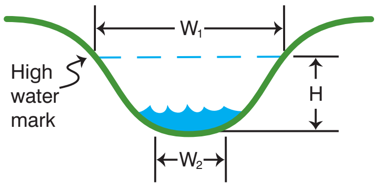
Figure 4-1. Roads culvert headwater-to-diameter ratio.

Culvert Sizing

Many procedures for sizing culverts are available. These approaches include the use of Talbot's formula, Manning's equation, inlet control nomographs, engineering field manuals, US Geological Survey stream statistics, etc. The use of such methods requires fairly extensive knowledge and research and should be left to engineers, hydrologists and natural resource professionals. In addition, Rocky Mountain watersheds tend to exhibit relatively high variability with regard to peak-flow estimates, which may result in grossly over or under designing a given stream crossing.

The Hasty Method is a simple procedure (Darrach et al, 1981) for sizing culverts. This method determines a culvert diameter that can handle approximate peak flows for small forested watersheds over at least a 25-year return interval/storm event (New Mexico State Forestry, 2002). This equation involves only three simple measurements, in feet, and provides a 100-percent safety factor (see Figure 4-2). These measures include: the width of the channel at the high water mark (W_1), the width of the channel at the bottom (W_2), and the height from the channel bottom to the high water mark (H). The sum of the two width measurements, W_1 and W_2, are multiplied by H to obtain a cross-sectional area. This area is then checked against Table 4-1 for the proper size culvert.

It also may be advantageous to look at existing areas on the



W_1 = Channel width at high water (feet)
W_2 = Channel width at bottom (feet)
H = Height of high water above channel bottom (feet)

Culvert area with 100% safety factor (square feet) $= H \times (W_1 + W_2)$

Figure 4-2. Hasty Method for calculating culvert end area. *Source: Colorado State Forest Service. (After: Darrach et al, 1981)*

Table 4-1. Round culvert pipe diameter required for given cross-sectional waterway area. *Haussman, 1978*

Cross-Sectional Area (square feet)	Required Culvert Diameter (inches)
1.80	18
3.10	24
4.90	30
7.10	36
9.60	42
12.60	48
15.90	54
19.60	60
23.80	66
28.30	72
33.20	78
38.50	84
44.20	90

property and/or neighboring locations with similarly sized watersheds and terrain to see what size culverts are being used and whether they appear functional. A good rule of thumb is to defer stream-crossing design and/or permitting involving regulatory issues to an engineering, forestry or hydrology professional when arch culverts, bridges or round culverts over 30 inches in diameter may be needed.

Figure 4-3. Stream that may need to be crossed and sized for a culvert.
Photo: R.M. Edwards

Waterway end area

W_1 = 1.5 feet

W_2 = 0.5 feet

H = 2 feet

Cross-sectional area ($feet^2$) $= H \times (W_1 + W_2)$

$= 2 \times (1.5 + 0.5)$

$= 4$ $feet^2$ with 100-percent safety factor

Reference to Table 4-1 indicates that a 24-inch diameter round culvert has a cross-sectional area of 3.1 $feet^2$,and a 30-inch diameter round culvert has a cross-sectional area of 4.9 $feet^2$. A 30-inch round culvert should handle the 4-$feet^2$ flow, as illustrated in this example.

However, if the gradient of the stream is less than 5 percent and is debris-free, the 24-inch diameter round culvert could be used. On the other hand, if it is anticipated that the road will be used as a higher standard mainline haul road with an associated higher value at risk, the 30-inch diameter round culvert should be used. If the surrounding watershed contains any recently denuded areas (e.g. fires and/or insect infestations), a larger culvert should be selected to handle any excessive debris or peak flows. Both options also would satisfy the maximum HW/D ratio of 1.0. When in doubt, seek professional assistance.

Figure 4-4. Culvert example 1. *Photo: R.M. Edwards*

Figure 4-5. Culvert example 2.

Culvert Design: Fish Passage

Remember that proper culvert design includes more than sizing for the 25-year peak flow. The design also should evaluate such stream features as:

- gradient,
- elevation in relation to the road grade,
- width (active or un-vegetated width),
- depth to bedrock,
- road alignment and grade,
- potential for sediment and debris movement during high flows, and
- potential for sediment stored behind an old culvert to move downstream with the new installation.

Following are factors to consider in order to protect fish passage:

- Don't force fish to jump in order to enter or pass through a culvert.
- Keep the culvert opening free of debris.
- Minimize culvert length.
- If possible, locate culverts on a straight part of the stream.
- Set culverts below stream grade so gravel can naturally accumulate in the culvert.
- Consider using natural or hand-placed gravel to facilitate passage of terrestrial species and benefit macroinvertebrates and other species important to the aquatic ecosystem.

Figure 4-6. Culvert example 3. *Photo: R.M. Edwards*

Figure 4-7. Culvert example 4.

Fish Passage

What design best accommodates fish passage? (The following are listed from best to least optimum.)

- Vacate or abandon crossing.
- Span the stream with bridges or use bottomless arches.
- Utilize fords for low traffic crossings.
- Simulate streambeds by using sunken or embedded culverts.
- Place bare culverts at zero grade and sink for backwatering.
- Consider a hydraulic design that incorporates weirs and baffle culvert designs.

Figure 4-8. Example of a low-traffic ford crossing.

Figure 4-9. Example of an arch culvert with baffles.

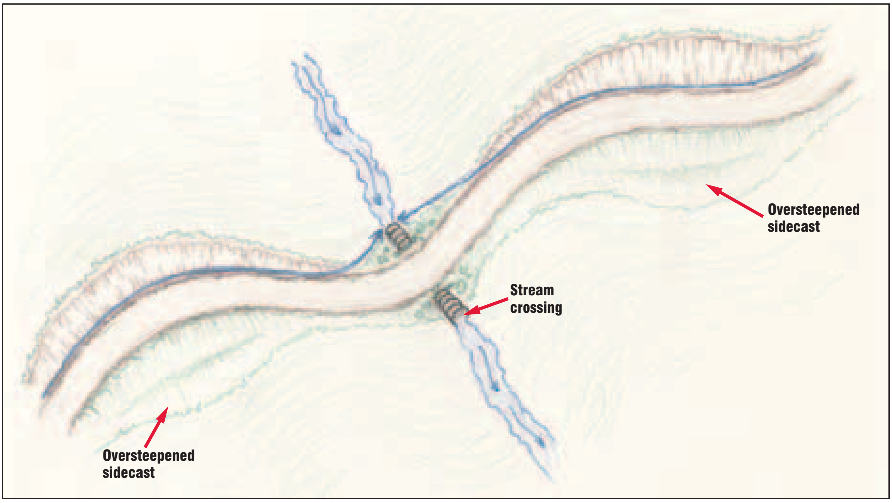


Figure 4-10. Road vacating – before.

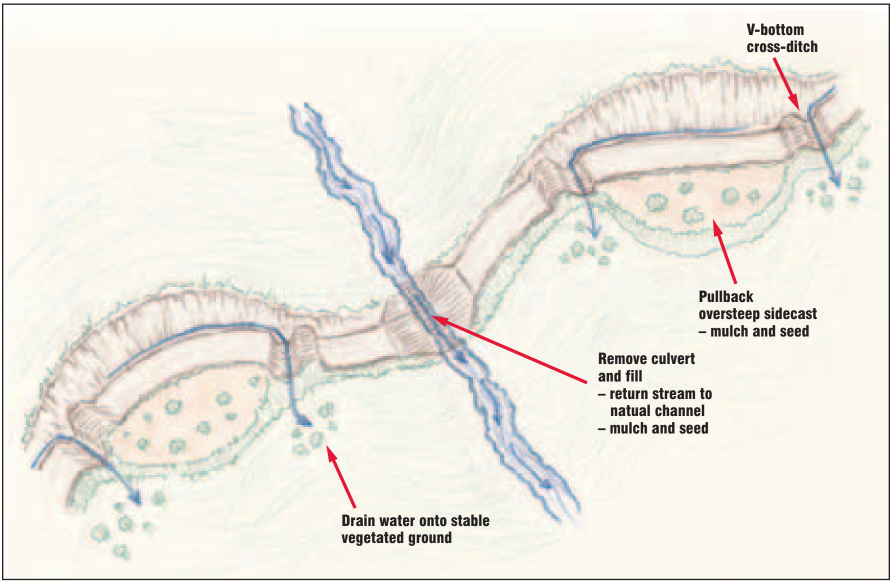


Figure 4-11. Road vacating – after.

Crossings that are barriers to fish movement should be scheduled for replacement or remediation. Seek technical assistance for replacement or remediation when determining whether to use a bridge, low-usage ford, open-bottomless arches or any other modified culvert design (see Figures 4-12 through 4-17).

Figure 4-12. Modular bridge with log railing. *Photo: Big R Bridge*

Figure 4-13. Bottomless arch culvert.

Figure 4-14. Example of low-tech solution for a temporary crossing using logs and lumber. *Photo: Kelly Rogers*

Figure 4-15. Example of a multiple culvert crossing with decorative retaining walls. *Photo: R.M. Edwards*

Figure 4-16. Example of a modular bridge with running planks. *Photo: Big R Bridge*

Figure 4-17. Example of a railroad car bridge with concrete abutments.

Ford Crossings

A ford is a stream-crossing option for gated roads with light service (see Figure 4-18). Access control is important in order to avoid damage to the approaches. These types of crossings seldom have year-round access due to potential water-quality issues. Unimproved fords, except those located on solid rock, usually are inadequate for truck traffic. Heavy vehicles break down stream gravel and mud can be transferred into the stream channel from vehicle tires.

Locating a ford:

- Bedrock streams are ideal for ford locations. Otherwise, stream bottoms must be armored with suitable rock.
- The size and shape of instream rock can indicate minimum armor rock requirements necessary to resist downstream movement. Rock should be bigger than that found naturally in the stream bottom. Clean, angular rock is preferred because of its capacity for interlocking.
- Gently sloping streambank approaches are preferred and should be rocked to minimize erosion. When practical, approaches should be perpendicular to the stream. They also should dip into and out of the stream, creating a concave shape that ensures the stream cannot be diverted out of its natural channel.
- Locate in riffle section between bend transitions and avoid locating fords on bends to the greatest extent possible.

Figure 4-18. Example of ford crossing.

Culvert Failure

It is important to note that very few culverts fail because the capacity of the pipe is too small. Most pipes fail because they become plugged, most often by floatable organic debris, as in Figure 4-19. Thus, a key factor in determining the resiliency of a robust culvert installation is how well it can handle floatable organic materials.

Make sure that fills over culverts are armored (see Figure 4-20). This is especially important for the upstream end or inlet of the culvert. The fill should be armored with clean, erosion-resistant rock greater than 6 inches in diameter. Remember, culvert repair should be done during low flows and the dry season to minimize environmental impacts.

Figure 4-19. Culvert with debris blocking opening.

Figure 4-20. Culvert with armoring.

Culvert Failure: Washouts

Washouts (see Figure 4-21) may be caused by stream flows that exceed the capacity of drainage structures, but most likely are a result of erosion and/or plugged culverts.

Issues include:

- culverts that become plugged where there is no overflow structure;
- undersized culverts;
- upstream debris that may plug culverts;
- a long, steady road grade below the stream crossing;
- no relief dip;
- flood waters that run down the road;
- "domino effect" downgrade from the crossing;
- ditch and road become a giant gully;
- downgrade cross-drains are overwhelmed; and
- potential effects on a substantial length of road segment.

Suggestions for preventing or reducing damage from washouts:

- Reduce the headwater-to-diameter ratio for the design return period events (i.e. from a 1.0 to 0.75). This will result in a larger-diameter pipe with a larger capacity for a greater peak flow.
- Armor relief dips with rock.
- Eliminate road-edge berms that keep water on the road.
- Construct a berm or plug in ditchline below stream crossings.
- Keep fills over culverts at a minimum.
- Remove old log-fill culverts.
- If possible, consider a bridge instead of a culvert.
- Consider adding a trash rack on or above the inlet to prevent plugging.

Log culverts pose one of the highest risks for fill failure; failure may be catastrophic, or if long-term, can result in chronic stream turbidity.

Figure 4-21. Washout caused by culvert failure.

Relief Dips

Culvert installation should be a well-designed and executed process. This is especially important when considering stream-crossing culverts, but ditch-relief culverts also should be included. These are designed structures and there is a probability that a storm may occur that can exceed the design, which in turn, will cause failure. The installation of these structures should be designed to fail with minimum financial and environmental effects. Instances may occur where a constant road grade may capture and divert flow from a stream down the road ditch, as in Figure 4-22. An armored relief dip can be constructed, as shown in Figure 4-23, to reduce impacts to the road if the culvert gets plugged or flow capacity is exceeded.

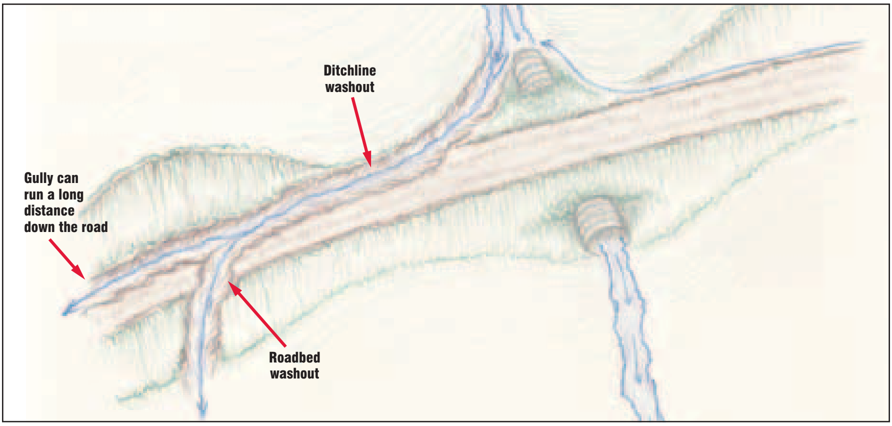


Figure 4-22. Washout by diversion of water down the ditch.

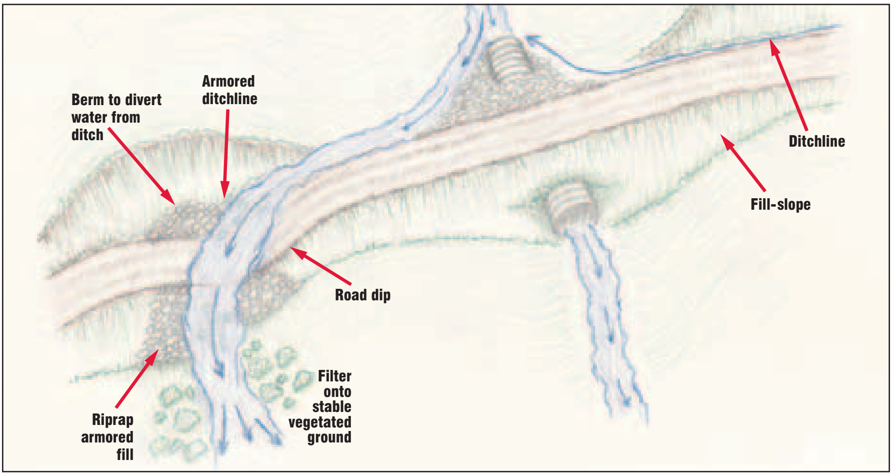


Figure 4-23. Armored relief dip.

Inspection/Maintenance/Repair

Photo: Colorado State Forest Service

Inspection/Maintenance/Repair

Why Inspect Roads?

A systematic, routine inspection, maintenance and repair regime will protect roads, save money and reduce harmful impacts on the environment, particularly streams and fish. Routine maintenance usually comes in the form of cleaning ditch culverts, shaping the road surface to maintain drainage, replacing and/or adding cross-drain structures, adding durable rock surfacing and controlling roadside vegetation that may interfere with drainage or vehicle use.

Non-routine maintenance includes emergency repairs during major storms that are essential to prevent washouts and landslides such as unplugging culverts and ditchlines, installing temporary overflows and redirecting floodwaters to less damaging areas.

There is a direct correlation between road usage and inspection: the greater the use, the greater the requirement for inspection to ensure that no problems arise. It is important to remember that new roads require careful consideration. Newly constructed forest roads, or roads with major repairs, have yet to "prove themselves." The location and number of drainage structures and quality of surfacing needs careful inspection to ensure the new road can withstand storms and will not result in unscheduled financial or environmental costs.

Of particular concern are any new or improved stream-crossing structures. In the example in Figure 5-1, an exposed bridge-fill next to a stream will erode during high flows, which will require armoring before the wet season.

Figure 5-1. Exposed bridge-fill next to stream.

Inspection Regime

Road maintenance is one of the keys to properly managed private forests. Owners are encouraged to maintain active and inactive roads in a manner sufficient to provide a stable running surface and keep the drainage system operating sufficiently so as to protect water quality. Additional information can be found in "Forestry Best Management Practices to Protect Water Quality in Colorado." (Colorado State Forest Service, 2010.)

This means road maintenance is the responsibility of the forest owner. They should perform an inspection and maintenance regime necessary to protect water quality, not just drivability. It also is the responsibility of the owner to control road access through the use of barriers and/or vacating roads.

Timely inspection of forest roads will help landowners identify problems and prioritize road maintenance and repairs. During inspections, a minimum of essential information will be collected to evaluate road usability and potential effects to water quality and fish habitat.

The objectives of a routine inspection, maintenance and repair regime of forest roads include:

- identifying poorly performing road components;
- preventing future road damage through prioritized maintenance;
- reducing long-term costs; and
- protecting water quality and fish habitat.

An assessment evaluates the road system to determine if it is performing properly. Specifically, the assessment should answer the following questions:

- What will the water do in the winter, especially when hauling during wet weather?
- What will happen during a flood?

Figure 5-2. *Photo: R.M. Edwards*

An effective inspection, maintenance and repair regime of forest roads will facilitate better management of family forest resources. Failure to maintain these roads can result in slope failure, erosion, stream sedimentation, damaged fish habitat and loss of access. One cannot over-emphasize the importance of robust, durable aggregate or gravel-surface forest roads. Roads should be a primary focus of attention for all private forests, with consideration for access, finances and the environment.

All forest roads and their drainage structures should be inspected, especially older or little-used roads. Frequent inspections are important, particularly in areas known to have past landslides, washouts and undersized culverts. Inspections should be made prior to wet weather, as in Figure 5-3, to ensure that the road and structures are functioning properly. Additionally, roads should be inspected prior to operations to ensure that adequate drainage and a stable, durable running surface exist.

It is imperative to make additional inspections during periods of heavy traffic use, particularly during wet weather, to diagnose drainage and road-surface problems. Another appropriate time for inspections is during heavy rainfall or rapid snowmelt and runoff events. Timing the inspection during these events provides an opportunity to check drainage-structure capacity during peak flow and mitigate any damage that may occur from a non-functioning structure such as a plugged or eroded cross-drainage culvert or a stream-crossing structure, as shown in Figure 5-4.

Dry weather, low-use roads that were used for a timber harvest and then abandoned or infrequently used roads, often are ignored and are not subject to regular inspection, maintenance and repair. These roads have the potential to result in substantial damage to the environment and ***must*** be included in a road-inspection regime.

Proper inspection, maintenance and repair can save time, money and the environment.

Figure 5-3. Preferred inspection method: inspect end of culvert prior to wet weather or heavy use.

Figure 5-4. Undesired inspection method: inspection of culvert after "blow-out."

Road Standards

Depending on the forest owner's objectives, forest roads can be designed in all sizes and shapes. For the purposes of this handbook, we list four planned uses, or non-uses, of forest roads.

- **Winter haul –** snow/wet weather use requires durable aggregate or gravel surfacing that can freeze and not break apart and also support intended design vehicles. Winter-use permissible on unimproved surfaces after fall freeze-up and prior to spring break-up (see Figure 5-5) or during dry winter conditions.
- **Summer haul –** dry weather use (see Figure 5-6).
- **Light –** pickup use only during dry periods.
- **Closed –** road currently closed.

Varying degrees of inspection, maintenance and potential repair are required to maintain the environmental and logistical integrity of the road.

Figure 5-5. Example of a winter haul road.

Figure 5-6. Example of a summer haul road.
Photo: Paul Cada

Assessment Form-Instructions

Following are some general guidelines to assist the party inspecting the road so that information can be relayed to another party. This can be valuable if a contractor is being hired to perform repairs and also may serve as a document to note particular locations in the road system that may warrant careful inspection during severe storms.

Some of the issues that may be encountered during a roads inspection will be discussed and illustrated, and possible solutions for resolving the problem will be identified. The list is not intended to be all-inclusive, but hopefully it will encourage owners to develop an effective inspection, maintenance and repair regime for their forest roads.

Forest Road Maintenance Needs Form

This form is intended to help family forest landowners and managers identify potential problems on their forest roads, note maintenance and improvements needs, and prioritize the actions that need to be taken to resolve the problem.

Directions:

- **Landowner:** Name of forest owner.
- **Road Segment ID:** Divide your forest road system into a logical segment that will allow you and your contractors to readily identify areas in need of maintenance.
- **Road Surface:** Note type of road surface (unimproved, improved, asphalt concrete, etc.).
- **Road Shape:** In-sloped, crowned, out-sloped, none.
- **Running Width:** Note typical road width, any narrow areas and the presence or absence of turnouts.
- **Planned Use:** Identify planned use (all season, dry use only, light duty, heavy duty, etc.).
- **Date:** Record the date that you assessed road conditions.

Checklist of Common Forest-Road Problems:

- **Location of Problem:** Where is the problem located? Identify a point of reference that will be meaningful for both you and your contractor.
- **Running Surface:** Potholes, ruts or berms, washboarding, erosion, wet spots.
- **Ditch:** Too shallow, excessive vegetation, blockage, overflows, erosion.
- **Cut/Fill:** Slumping, erosion.
- **Grade:** Too steep (9 percent or more, 5 percent or more on corners); sudden change in grade that would be sufficient to high-center a vehicle.
- **Brush/Vegetation:** Brush encroaching on road, grass/weeds/ brush growing in road surface, trees providing excessive shade (preventing road surface from drying) or excessive leaf fall.
- **Waterbars (and rolling dips):** Too shallow, improper angle, rutted, eroded.
- **Ditch Relief Culverts:** Blocked/clogged, failed to drain ditch, damaged, eroding, downslope erosion.

- **Stream Crossings:** Blocked/clogged, damaged, eroding, too small, blocks fish passage.
- **Filtering:** drainage structures funnel water directly to streams, road too close to streams.
- **Action Needed/Priority:** Note what you should do to correct the problem and how soon it needs to be completed.
- **Assessment:** At a minimum, forest roads should be assessed annually prior to the onset of wet weather and should be well maintained at all times.

An effective system for forest road inspection, maintenance and repair requires a systematic document that forest owners can use to locate, identify, document and prioritize issues involving their roads. Through utilization of the Forest Road Maintenance Needs Form (see Figure 5-8), forest owners can record pertinent information relating to their road system in a systematic, simplified, logical process. Utilizing the following form will help forest owners maintain a robust and well-functioning road system.

Figure 5-7. Example of a newly constructed waterbar that may require future assessment. *Photo: Keb Guralski*

Forest Road Maintenance Needs Form

Landowner ____________ Road Shape ____________ Date ____________

Road Segment ID ____________ Running Width ____________ Page ______ of ______

Road Surface ____________ Planned Use ____________ Other ____________

Location of Problem	Problem									Action Needed & Priority
	Running Surface	Ditch	Cut/Fill	Grade	Brush/Veg	Water-bars	Ditch Relief Culverts	Stream Crossings	Filtering	

Figure 5-8. Forest Road Maintenance Needs Assessment Form.

Location of Problems

Once a problem has been discovered, it is imperative that the owner return to the location as soon as possible to perform the required maintenance or repair. If inspecting a road during a storm, a problem most likely will be discovered from the seat of a pickup. If the necessary tools are not immediately available, it will be necessary to return to the location as soon as it is possible and safe to do so.

However, if potential problems are discovered during an inspection in the middle of the summer, the exact location may not be quite so easy to locate. For example, problems such as a plugged ditch-relief culvert or an eroded waterbar may be hidden by vegetation. If these cross-drainage locations are not permanently marked in some manner, it could be more difficult to locate them during a return trip.

Figure 5-9. Miscellaneous measuring devices. *Photo: Lisa Mason*

The preferred method of inspecting a road segment is to measure distance from a logical starting point such as a gate or road intersection. Distance is measured by slope, not the actual horizontal distance. This can be done by pacing or through the use of a belt/hip chain, tape, wheel or special odometer (Figure 5-9).

Figure 5-10. GPS with Forest Road Maintenance Needs Form. *Photo: R.M. Edwards*

Engineers measure road segments by the station, with each station spaced at 100-foot intervals. A position within the road system is designated by first listing the reference station number and then listing the distance to a given point between stations. These values are separated by a +. The distance at the beginning of the road system is zero, thus the starting station is designated as 0. The distance from a reference station is represented by two integers. If the position is at the station, then the distance is zero feet from the starting, or reference, location, making the designated distance 00. A position at the beginning location of the road would be represented as 0 + 00. If the location is at the next station, station #1 within the road system, the position would be represented as 1 + 00. If a problem is identified at a point 50 feet after station #1, the location would be transcribed as 1 + 50. Forty feet between the third and fourth station would be designated as 3 + 40, and so on.

A precise, measured distance to the identified problem is not as important as the individual's ability to locate the site. GPS waypoints using various coordinate systems (i.e. latitude and longitude or Universal Transverse Mercator) also may be used if access to such equipment is available. Flagging, noting a significant structure along the road such as a sign or T-post (see Figure 5-11), an unusual geographic feature, or anything else that the inspector can note in the **Forest Road Maintenance Needs Form** will enable them to locate the site.

Figure 5-11. T-posts marking culvert location on road for Forest Road Maintenance Needs Form.

Road Segment

Forest roads can be inspected by road segment and intended use. The road system should be divided into logical segments that will allow the owner or party inspecting the road to identify areas in need of maintenance and repair. Once the problem has been located and identified, it is advisable to use the **Forest Road Maintenance Needs Form**, which will allow the inspector to record pertinent information, determine a remedy for the problem and prioritize the action based on potential financial and environmental impacts.

Dividing the road system into individual segments is fairly straightforward, provided the road segment under consideration is a spur road or the only road on the forest property. The entire road system should be inspected, monitored, maintained and repaired on a consistent, continual basis, but special attention is required during heavy use and/or when hauling during wet weather.

In these instances, if the road segment to be used is a portion of a larger system, then it may be helpful to develop another method of delineating the portion of road in question. In these situations, a survey from drainage point to drainage point will be the best option. Drainage points may be a road junction or drainage divide with no associated drainage structure. Drainage points are locations where surface-drainage water crosses the road or a place where drainage waters flow in opposite directions. When a road segment is delineated by this method, the segment is divided by waterway rather than individual road.

Figure 5-12 illustrates road segments divided by waterway. Numbers indicate the changing direction of the flow of water and letters represent the type of drainage system.

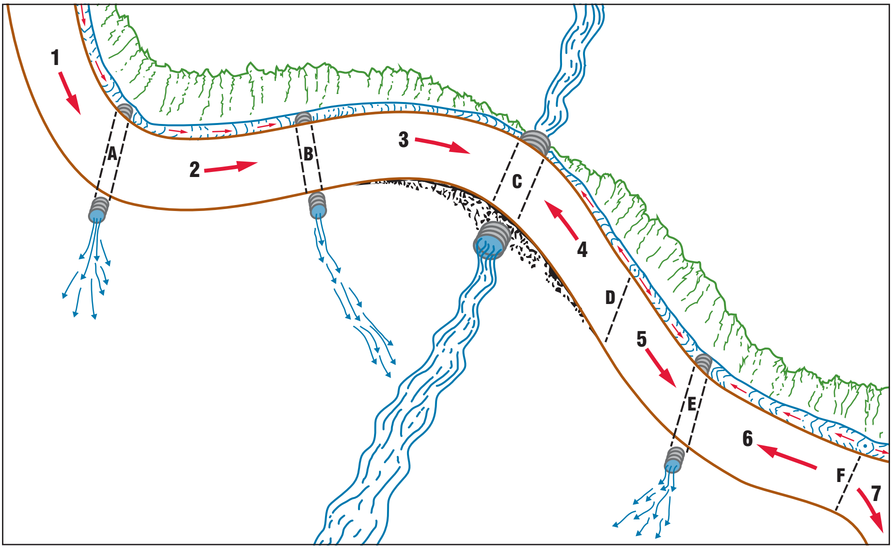


Figure 5-12. Road segments divided by waterway.

Inspecting forest roads should identify and prioritize repairs for any problems, including:

- drainage such as downcutting in ditches;
- drainage on steep slopes;
- drainage structures that are damaged or not working properly;
- evidence of erosion or failure of the road surface, fill or cut-slopes;
- rutting, gullies or potholes in the running surface;
- arc-shaped cracks in fills;
- direct sediment discharges into streams; and
- other potential sources of drainage or stability problems.

Figure 5-13. Example of priority repair involving fish passage. *Photo: Craig Hansen*

Priority repairs involving stream crossings and fish passage include:

- culvert outlet drops (i.e. one-way barriers) in fish bearing streams (see Figure 5-13) or complete barriers to fish movement;

Figure 5-14. Example of priority repair involving a wood culvert. *Photo: Dan Wand*

- non-embedded culvert with gradients above 0.5-percent slope;
- old log fills or wood culverts (see Figure 5-14);
- potential for washout due to an undersized structure and/or a long, steady grade below a stream crossing;
- erosion around culvert inlets or outlets; and
- structural deterioration of culverts.

Priority repairs involving sidecast failures and/or slope stability include:

- nearby slope failures (see Figure 5-15);
- high cut-slopes (over 15 feet high);
- sidecast over two feet deep on steep slopes;
- fills supported by trees and/or organic debris; and
- arc-shaped cracks in fill or roadway.

Figure 5-15. Example of slope failure.

While these major repairs are a high priority, there are instances where repairs become nearly impossible. If other access is possible, serious consideration should be given to temporarily closing or vacating the road, as in Figure 5-16.

Figure 5-16. Temporary road closure.

Shape

When determining the geometric shape of forest roads, owners should be less concerned whether the road is crowned, in-sloped, out-sloped or a no-shape road than whether they have employed the proper methods for water diversion and dissipation. Figures 5-17 and 5-18 below illustrate examples of road segments with and without proper water diversion and dissipation methods. If a future, large-scale timber harvest is being planned and the owner feels the extent of the operation warrants major road repair or reconstruction, then engineering the road to achieve a definite shape makes considerable sense. However, most operations on private forests are conducted on existing road systems and those roads are sustained through a program of additional maintenance and, when necessary, repair.

It warrants repeated attention: If forest roads will be used during wet-weather operations, it is imperative the road system be evaluated *before* conducting any operations. This is especially important when streams become an issue. Stream turbidity and sedimentation are better managed through a stable running surface and well-maintained surface drainage system than through maintenance and repairs after the fact. A stable running surface will eliminate the need for emergency repairs.

Figure 5-17. Example of road segment *with* proper water diversion and dissipation methods.

Figure 5-18. Example of road segment *without* proper water diversion and dissipation methods.

Clearance and Planned Use

The intended use of a forest road is a primary factor in terms of clearance. Clearance relates to vertical and horizontal clearance. It is far easier to develop and maintain vertical and horizontal clearance for a pickup than a loaded log truck. When in doubt as to the future use of a forest road, it is best to overestimate the needed clearance. This philosophy can be extended to all design and maintenance issues related to roads: when in doubt, manage for extreme use and weather events. It is possible that over the long-run, owners will save time, money and impacts to the environment.

Figures 5-19 and 5-20 below illustrate a well and poorly designed forest road in terms of vertical and horizontal clearance. The latter photo shows that while the road certainly is adequate for a pickup, it does not have the proper vertical or horizontal clearance necessary to accommodate log truck traffic.

Figure 5-19. A well-designed forest road with adequate clearance.

Figure 5-20. A poorly designed forest road in terms of clearance.

Road Surface

Once the road segment has been determined and the general condition of the road surface has been evaluated, it is time to identify specific/individual issues in the road segment. There is no particular order of precedence in identifying problems. Topics of interest/concern are encountered as they become available while traversing the road.

It is important to consider such issues as potholes, ruts or berms, washboarding, erosion and wet spots. Washboarding and smaller potholes are an indication of a poorly maintained running surface and not necessarily a problem in terms of the ability of the road to stand up under heavy use and wet weather (see Figure 5-21). Regular grading and possibly additional rocking can solve these problems quickly and with relatively little expense.

Figure 5-21. Example of poorly maintained road with excessive washboarding. *Photo: R.M. Edwards*

Routine maintenance on low-use roads differs from that on roads that have more traffic. These low-use roads, as shown in Figure 5-22, often have no definite geometric shape and seldom are graded. Grading is done with a farm tractor or by back-blading with a bulldozer, and these roads often have vegetation growing in and alongside the roadway.

Figure 5-22. Example of a low-use road.

Ditches

Proper ditching of crowned, in-sloped and no-shape roads is essential for properly functioning ditch-relief culverts. In the past, grading (pulling) ditches to remove unwanted vegetation was considered proper road maintenance. Pulling a ditch with a grader can result in more erosion than a vegetated ditch. It is best to pull the ditch only when it is not functioning properly. In this case, benign neglect could have a positive outcome.

When ditching roads, be sure ditches are at a sufficient depth to handle a high-intensity rainfall. Even under the best conditions, debris will accumulate, thus making adequate depth even more important. Some considerations involving roadside ditches are included in Figures 5-23 through 5-25.

Figure 5-23. The ability of the ditch to handle high-intensity storm runoff from roads; in this case, a roadside ditch is too shallow.

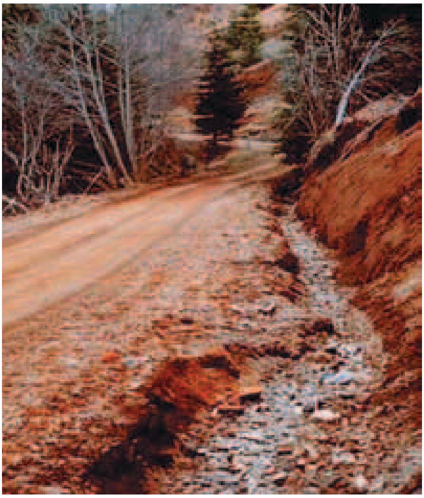


Figure 5-24. Excessive down-cutting of the ditchline likely is the result of too few ditch-relief culverts.

Figure 5-25. An example of a durable aggregate surface road with a well-marked ditch-relief culvert and a vegetated, debris-clean ditchline.

Inspecting a cut-slope should determine whether it is functional and not eroding. It also should determine the risk for problems in the future (largely determined by the height). The cut-slope may be eroding and filling the ditch and/or narrowing the road surface. Figures 5-26 and 5-27 illustrate two examples of cut-slope erosion.

The most common problem encountered by cut-slopes involves obstructing the ditch flow. This involves debris moving to the ditch-relief culvert and causing it to become plugged. What started out as relatively benign cut-slope erosion caused a plugged culvert, which might

Figure 5-26. Cut-slope erosion example 1.

Figure 5-27. Cut-slope erosion example 2. *Photo: R.M. Edwards*

result in the loss of a segment of road. Once this scenario develops, unless the road is being used for wet-weather hauling, these major road repairs often are not tackled until the dry season.

When a mid-slope road develops severe erosion and/or slumping, the problem can become chronic and result in the need for constant inspection, maintenance and repair. Additional ditch-relief culverts may become necessary, along with backup devices such as waterbars or rolling dips. If the problem persists and becomes a chronic problem for fish and their habitat, the only option may be a road closure and/or relocation.

If a ditch becomes plugged due to erosion of a steep and/or high cut bank, long-term solutions may involve armoring, as shown in Figure 5-28, reducing the slope of the cut bank and/or grading the ditch. In this case, excavating or grading needs to be done during the dry season. Temporary measures may involve shoveling to remove enough debris to ensure adequate drainage. Keep in mind that once a problem develops in a particular road location, the possibility increases that there will be issues in the future, thus stressing the importance of timely and careful inspection.

Figure 5-28. Example of cut-bank armoring.

Grade

Road grade is the difference in elevation between two points along a road surface. Grade is positive (+) uphill and negative (-) downhill. Grade is expressed in percent (%), the vertical change of a road elevation for a given horizontal distance along the road. For example, the change of grade uphill (+) 10 percent would be a change in elevation of 10 vertical feet in a distance of 100 horizontal feet. A negative road grade in the direction of a loaded log truck is called a favorable grade. A positive grade in the direction of a loaded log truck is called an adverse grade.

On unimproved surface roads where the soil moisture and compaction are ideal, loaded log trucks have negotiated adverse grades up to 20 percent. However, ideal conditions are rarely met, so competent contractors usually will keep road grades below 12 percent without special surfacing.

Following are road-grade classifications:

- A flat grade is 0 to 1 percent.
- A gentle grade is 2 to 4 percent.
- A moderate grade is 5 to 8 percent.
- A steep grade is 9 to 12 percent.
- A very steep is grade over 12 percent.

Figure 5-29. Example of unimproved road with moderate grade. *Photo: Colorado State Forest Service*

The grade on any forest road should be at least 2 percent to facilitate drainage. Flat roads do not drain properly and even small ruts in the running surface can cause water to collect on the road. This can result in water saturating the subgrade, greatly compromising the structural integrity of the road and leading to major damage if used for wet-weather operations. While flat is not necessarily good in terms of road grades, neither is too steep. There is a direct correlation between steepness of the road grade and the necessity for inspection, maintenance and control of surface-water drainage and dissipation.

In order to negotiate steep road grades, proper surfacing becomes even more important. A typical combination of rock on forest roads consists of a 3-inch or 6-inch base with a surface layer of 1½ inch, minus durable rock. On steep grades, it may be necessary to spread smaller-diameter rock as surface rock in order to achieve adequate traction. Three-quarter-inch minus surface rock may be used for this purpose. In most instances, forest owners should not spread rock on dirt roads that is too small in diameter due to the volume necessary to develop a base capable of withstanding heavy, wet-weather hauling.

Brush/Vegetation

Brush and vegetation can present issues in terms of clearance and road drainage. Grass allowed to grow in the middle and along the shoulders of the road can impair proper water drainage on an otherwise properly constructed geometric road shape (see Figure 5-30). These low-usage roads present potential problems involving roadside vegetation. During the wet winter months, vegetation growing in the middle and side of the road can serve as a channel to divert water. If left unattended, it can result in substantial damage to the road surface, possibly exceeding the capacity of the ditch-relief system when water is diverted past the nearest water diversion structure to another structure further down the road. If the problem is allowed to persist, chronic stream sedimentation and possible damage to fish habitat can occur.

Road and surface drainage can be compromised if passage is impeded by overhanging brush. In order to avert brush rubbing against the vehicle, drivers may move too far to the shoulder of the road, causing possible rutting or creating a berm that impedes the passage of water off the road surface. When leaf foliage is present, brush also can be a safety issue, blocking visibility of any oncoming traffic.

During the dry season, roadside vegetation must be considered in terms of wildfire hazards. The growing season for grass is earlier and the vegetation grows faster than brush and trees. The dead and drying grass along the road can create a fire hazard long before fire becomes a threat in the forest.

Figure 5-30. Brush and vegetation on the road can become a maintenance issue.

These structures are the primary method of water diversion on unimproved roads and oftentimes are necessary components of a low-use, improved surface road (see Figure 5-31). A substantial number of roads on private forests were excavated as cheaply as possible, to create a level running surface with a bulldozer, excavating the smallest amount of soil possible. Oftentimes, the result was/is a road surface that has been excavated below the forest floor, making dispersal of surface runoff extremely difficult. The resulting erosion and required maintenance of the road contributed to the displacement of soil within the road prism, further exacerbating the problem. These roads can become channels for drainage and a significant source of chronic stream sedimentation.

If used continually, the only method available to divert water from these types of roads is through the use of a deep and extensive waterbar system. Frequency, depth and excavated length away from the road are factors that need to be considered. The system will fail if waterbars cannot be excavated an adequate distance away from the road, thus allowing water to drain far enough from the road prism and not allowed to re-enter at some other point.

Figure 5-31. Example of an improved, through-cut road that may require waterbars.

Figure 5-32. Example of waterbar being constructed on a low-use unimproved surface road.

Rolling Dip: Rubber Bar

When incorporating a waterbar/rolling dip system on your improved surface roads, there are some things that can make them more user friendly (see Figure 5-33).

Consider the following guidelines:

The topography of most forest roads will reveal a series of steeper grades combined with a number of ridges/ and relatively level roadways. If the distance between flatter areas lies within the suggested waterbar spacing, place your waterbars on the flatter areas. Ingress/egress into them will be easier because you don't have to accelerate/decelerate your vehicle on steeper slopes. The chances of spinning your tires increases when you try to accelerate out of a waterbar placed on a steep slope, disturbing the roadbed and throwing loose material into the bottom of the waterbar. This will reduce the depth of the dip, increasing the chances of failure in a heavy rain.

Whenever possible, construct waterbars on a curve in the road. Reasons are twofold: first, in the event of failure, there is a greater chance the water will cut a channel off the roadway because it will have been partially diverted towards the side of the road before the waterbar totally failed. Secondly, when placed on a curve, a vehicle will enter the dip at a straighter angle than if the bar was placed on a straight stretch of road. (The curve in the road accounts for part of the deflection angle of the waterbar). This helps avoid "rocking" in and out of a bar, which is especially important for top-heavy trucks and vehicles.

Consider a "semi" rolling dip/ waterbar. By constructing your bars/dips on flatter stretches of the road, you can make the bars a little shallower and your dips slightly lower. This reduces maintenance costs, makes the road easier to maintain, makes ingress/ egress smoother and impacts less road area, thus reducing erosion or failure.

Figure 5-33. An example of how to make a conventional waterbar a bit more user friendly.

When inspecting ditch-relief culverts, the following factors should be considered:

- Blocked/clogged structures
- Ditchline erosion
- Downslope erosion

As with any inspection, maintenance and repair regime, the dry season is best suited for these activities. Most private forest owners conduct the vast majority of their activities during the dry months, often neglecting routine maintenance and repair of their roads and drainage structures until a problem arises and is detected during the wet season.

Figure 5-34. A partially plugged culvert.

Before the autumn rain and snow begins, inspecting and performing maintenance on this partially plugged culvert (Figure 5-34), will prevent a total blockage, which would have resulted in damage to the road surface, in addition to stream sedimentation and turbidity.

Inspection and repair "after the fact" becomes difficult, and in the case of wet-weather hauling, activity is likely to cease. In this instance (Figure 5-35), a plugged culvert has caused the roadbed to become saturated and water has seeped around the culvert causing the road surface to slump, making it a point of chronic stream turbidity. Wet-weather hauling compounds the environmental damage that already has occurred and leads to future financial losses.

Figure 5-35. Saturated roadbed; the result of a plugged culvert.

Culvert Repair

Figure 5-36. Crushed end of steel culvert.
Photo: R.M. Edwards

The most common damage to steel culverts is restricted waterflow resulting from a crushed end (see Figure 5-36). If not totally crushed, a handyman or hydraulic ("bottle") jack can be placed in the steel culvert and then jacked back to near its original shape. Plastic culverts cannot be repaired using this method.

If rusted steel culverts (see Figure 5-37) are not replaced, a total failure of the culvert eventually will occur, leading to financial and environmental costs. The structural integrity of a steel culvert can be tested using a steel bar (a piece of rebar is a popular choice for this purpose). In these instances, the longer lifespan of the plastic culvert has an advantage over steel.

Figure 5-37. Rusted culvert.

Ditchline Erosion

Excessive ditchline erosion likely is the result of inadequate spacing. Too much water is being carried too far down the side of the road to prevent erosion. If a cross drainage structure is in proximity to a stream, it can be a point of turbidity and sedimentation. The only long-term solution is to install additional cross-drainage structures.

In the example shown in Figure 5-38, one should consider additional cross-drainage structures.

Alternatively, if ditchline slumping occurs, as shown in Figure 5-39, water will be diverted onto the road surface. Waterbars, rolling dips or rubber bars will be required because of the inability to keep the ditchlines clean and functioning properly. If in-road water diversion structures are in proximity of a stream, filtering also may need to be incorporated with these structures to prevent sedimentation.

Figure 5-38. Excessive ditchline erosion.
Photo: Dan Wand

Figure 5-39. Ditchline slumping along cut bank.
Photo: R.M. Edwards

Downslope Erosion

Downslope erosion can be the source of sediment to streams, as shown in Figure 5-40, and may be the forbearer of catastrophic road damage. Various methods can be used to prevent these types of problems, including the use of half-round pipe (plastic or steel can be used; steel shown in Figure 5-41), pipes that extend beyond the fill area (Figure 5-42), rip-rap (Figure 5-43), or large and stable woody debris. Please refer back to the "Drain" and "Dissipate" sections in Tab 2 (Cross-Drainage Structures) for more details on culvert-velocity inhibitors.

Figure 5-40. Example of a culvert contributing to downslope erosion.

If left unattended, erosion may continue. What began as the formation of a small gully below the road has become a full-scale road failure.

Figure 5-41. Prevention of downslope erosion utilizing steel half-round pipe.

Figure 5-42. Prevention of downslope erosion using an extended plastic pipe length.

Figure 5-43. Prevention of downslope erosion with rip-rap.

When issues arise during the inspection of a stream crossing, it is advisable to consult a technical specialist and a CSFS forester. Crossings that are barriers to fish movement should be scheduled for replacement or remediation. As with ditch-relief culverts, blocked, clogged, damaged or eroding pipes are potential problems that should be considered.

The primary issues related to stream crossings and fish passage are jump heights greater than ½ foot and water in a bare pipe that is flowing at a velocity that is either too shallow too deep (see Figures 5-44 and 5-45 below). It is important to note that a non-perennial stream also may be a fish-bearing stream. In addition, riparian areas along stream courses generally contain the most productive wildlife habitat in the forest. Information regarding fish-bearing streams can be obtained from local Division of Wildlife and/or U.S. Fish and Wildlife Service personnel (see "Assistance" section).

Figure 5-44. Stream crossing with excessive jump height and stream velocity.

Figure 5-45. Stream crossing with reasonable jump height and stream velocity.

Filtering

Filtering is an extremely important component of a forest owner's road inspection, maintenance and repair regime. Filtering can be a permanent measure or a temporary part of the road system, as shown in Figures 5-46 and 5-47, respectively. Without a functional filtering system, roads and cross-drainage structures can be sources for sediment delivery and stream sedimentation, potentially impacting fish and their habitat.

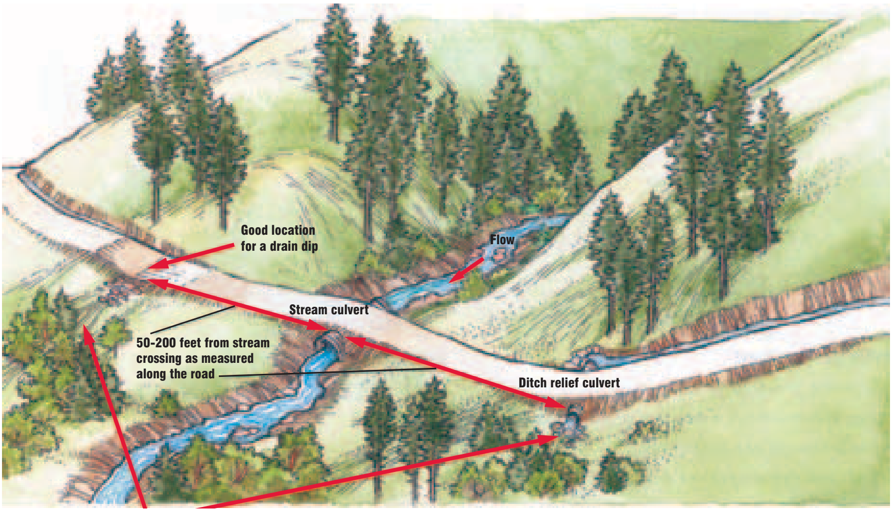


Figure 5-46. Illustration of a temporary measure as part of the sediment filtering system.

Miscellaneous methods of sediment filtering include: geotextile silt fences, hay bales, mulching, rip-rap, seeding and slash filter rows. The most important issue pertaining to temporary filtering systems is the need for possible replacement and/or repair during the wet season.

Figure 5-47. Illustration of permanent road structures as part of the sediment filtering system.

Berms

In some instances, a barrier to water drainage, considered harmful under most situations, actually may help prevent damage. If a berm exists alongside a road at a stream crossing, as illustrated in Figure 5-48, it may be better to divert the water down the road and past the stream until it can be diverted onto a non-compacted and/or vegetated forest floor. This is not an optimal solution to the problem, but oftentimes the best alternative may be the one that causes the least amount of damage. Snow berms should be broken up as needed to provide drainage on roads during and after winter operations.

Figure 5-48. An unimproved road with native soil berm.

A primary purpose of this publication is provide information for individuals to develop a systematic maintenance regime that leads to timely repair of forest roads, but these duties need to be performed properly. In this instance, as illustrated in Figure 5-49, maintenance of a forest road through grading has developed a berm along the edge of the road. As a result water remains within the road prism rather than diverting onto the forest floor.

Figure 5-49. An improved road with aggregate berm.

Road Closure and Decommissioning

At times, forest road segments may need to be temporarily closed or decommissioned. These roads may have been poorly designed and/or located in the past, and may be causing erosion problems or perhaps have not been utilized for a period of time. In other cases, a different access route may be planned, requiring this section of road to be closed in order to eliminate the need for further maintenance.

Road closure usually means that a gate or barrier is installed, water bars are constructed, and the road surface is seeded. Decommissioning, involves removing drainage structures and modifying/restoring the road cross-section or prism.

Zeedyck (2006) lists a three-step process for road decommissioning:

1) Block the road to further use of any type, whether intentional or accidental.
2) Install well-planned, properly positioned drainage structures that re-establish the natural drainage pattern characteristics of the pre-roaded condition.
3) Install special drainage features to protect or preserve sensitive sites such as springs and spring seeps from surface runoff intrusion and sedimentation.

Some roads may require full-bench recovery in order to restore the surrounding topography to its original configuration and slope. This type of closure can be very expensive and requires tracked excavation machinery to retrieve the original fill material, which then is placed onto the cut-slope area. Proper and timely native re-vegetation and mulching of recovered areas are absolutely essential in order to prevent soil erosion and establishment of invasive plant species.

Figure 5-50. Example of a road that may require closure or decommissioning.
Photo: Keb Guralski

Dust Abatement/Control

Dust is another forest road maintenance issue that occurs specifically during the drier months (see Figure 5-51). Depending on level of use, types and weight of vehicles using the road, and the average vehicle speed on the road, dust can create numerous problems. Problems include reduced visibility resulting in potential safety hazards, air quality/health issues for road users involving particulate matter, loss of soil resources through wind erosion, localized siltation and increased maintenance on equipment and vehicles.

Figure 5-51. Example of dust created during a harvest operation. *Photo: Paul Cada*

The most common solution to an existing or potential dust problem is the use of dust suppressants (see Figure 5-52). These agents "work by either agglomerating the fine particles, adhering/binding the surface particles together, or increasing the density of the road surface material" (Bolander and Yamada, 1999). Some other benefits to using these suppressants include reduced loss of fines, and thus, surface course strength; reduced loss of aggregate due to "whip off" to inslope or edge of road; and general reduced need for road grader/blade maintenance.

The USDA Forest Service recognizes seven basic categories of suppressants (sometimes called palliatives):

- Water
- Water-absorbing products/salts
- Organic petroleum products
- Organic nonpetroleum products
- Electrochemical products
- Synthetic polymer products
- Clay additives

Figure 5-52. A dust-suppressant spray truck applying magnesium chloride. *Photo: EnviroTech Services, Inc.*

The most common dust suppressant used in Colorado (and probably the western United

States) is magnesium chloride (MgCl). This chemical is considered a water-absorbing salt suppressant, along with calcium chloride, ammonium chloride and sodium chloride. All are considered hygroscopic products, which means they absorb and pull moisture from the air, keeping the road surface damp and thus minimizing dust formation.

Other alternatives to MgCl can be used, however, some may not be readily available and some of the newer alternative formulations may be substantially more expensive. The best advice is to check with your local contractor/supplier regarding availability and cost. In certain cases, a lower-impact product may be necessary in sensitive areas.

Figure 5-53. Preparation of road surface prior to dust-suppressant application.
Photo: EnviroTech, Services, Inc.

Road-surface preparation, as shown in Figure 5-53, can be important prior to application of dust suppressants. First, your aggregate or gravel should have good gradation of particle sizes with sufficient fines. Second, it is best to loosen one to two inches of the existing surface prior to application to allow optimal penetration. Third, dust suppression should not be applied if rain is likely to occur. Fourth, it is important to keep traffic off the surface for at least two hours after application. And finally, make sure that moisture on the road are at optimum levels before application. Do not apply to dry aggregate or gravel.

Figure 5-54. Rear view of a dust-suppressant spray truck, illustrating the spray nozzle application apparatus. *Photo: Desert Mountain Corporation*

Impacts to water quality, aquatic habitat and surrounding plant communities need to be addressed if a dust-abatement program is instituted. In some cases, proper buffer zones may be required in sensitive aquatic and/or riparian areas or if they are adjacent to susceptible plant species. An example would be MgCl; trees susceptible to damage from this chemical include ash, hemlock, maple, pine, poplar and spruce.

After a road inspection has been performed, an action plan may be necessary to prioritize the necessary maintenance and repairs. A maintenance issue such as a rough-running surface will be a low priority, while a collapsed culvert during wet-weather operations necessitates immediate repair.

If the road system is being inspected for the first time, it is important to look for damage that might have occurred in previous years. For example, a rutted, unimproved road indicates the need for additional waterbars. If it is in the proximity of a fish-bearing stream, the road may be the source of chronic sedimentation during the wet season. A road also may have been used for a timber harvesting operation in the past, but the forest owner has an ongoing responsibility for maintaining that road to protect water quality.

The concrete culvert shown in Figure 5-55 would be considered a low priority, as it is functioning adequately, is free of debris and erosion is minimal.

A rusted culvert, as shown in Figure 5-56, may be functioning, but should be an intermediate priority for replacement due to its impending collapse and failure.

A plugged or obstructed culvert (Figure 5-57) will always be a high priority during a road inspection.

Figure 5-55. Concrete culvert; low priority.

Figure 5-56. Rusted culvert; intermediate priority.

Figure 5-57. Plugged culvert; high priority.

Wet-Weather Operations

Photo: Paul Cada

Wet-Weather Operations

Wet-weather operations normally take place when rainfall or thawing occurs. In Colorado, this typically includes the period from March through June. Wet periods from individual storms with sufficient rain to result in deep rutting resulting from heavy truck use and periods of snowmelt also are considered wet weather.

It is advisable to follow these specific preventive practices when roads are used during snowy and wet weather:

- Place durable surfacing or other effective measures on road segments that are connected to streams (see Figure 6-1).
- Set a specific threshold when operators must cease hauling.

Following these practices will help mitigate the negative effects of using roads on any type and size of stream crossing during wet periods. It is advisable to comply with these practices when placing durable surfacing on any road segment that drains into streams.

Forest owners should discontinue hauling operations on a road segment that drains into a stream because it can result in a visible increase of turbidity. If a visible increase in stream turbidity occurs, the operator should cease road use immediately and make effective repairs using methods that provide additional drainage and surfacing.

Figure 6-1. Dump truck placing aggregate on road.

Sediment Delivery

Even under the best of conditions, roads need to be periodically maintained and repaired. Roads represent unnatural changes to the forest landscape, and nature continually works at reestablishing a natural landscape. When adverse weather conditions exist, as illustrated in Figure 6-2, roads require regular maintenance because damage that is not immediately repaired can lead to serious financial and environmental impacts. After freezing temperatures and thawing occur, roads are extremely susceptible to erosion and degradation. If at all possible, discontinue heavy use for several days after freezing and thawing events.

This section deals with forest roads that are used during the wet season and some of the issues that need to be considered in order to avoid or minimize damage. During regular use, a durable aggregate or gravel surface road requires attention, and it should be remembered that damage will occur when heavy traffic operates on these roads during inclement weather conditions.

Roads should be located where the impact on streams and fish habitat can be kept at a minimum. If possible, avoid steep slopes, slide areas, high landslide hazard locations, wetlands, resource management areas or other environmentally sensitive areas. Special emphasis should be placed on minimizing stream crossings. When stream crossings cannot be avoided, seek professional assistance and contact your nearest CSFS forester.

Figure 6-2. Adverse weather conditions can create adverse road conditions.

Surfacing

Properly functioning cross-drainage structures and stream-crossing structures (when applicable) are the key elements in a robust road drainage system.

Following are the various types of forest road surfaces:

- **Unimproved:** an unsurfaced road
- **Improved with old rock:** a road on which the surface has not been maintained and in place for a long time; examples include muddy rock or sandstone surfacing.
- **Improved with non-durable rock:** a road that may contain old rock or clean, durable rock, but is not of sufficient depth to withstand heavy traffic or wet-weather use.
- **Improved with durable rock:** a road with clean, hard rock without many fines and of sufficient depth to hold up to all wet-season traffic.
- **Paved:** a road with asphalt or concrete surfacing.

Remember to inspect roads in the context of how they are going to be used. If an old rock or non-durable rocked road is going to be used for intermittently or for light traffic and smaller vehicles, the condition of ditch- relief structures will take precedence. If the road is to be used for wet-weather hauling, surfacing and ditch relief structures are of equal importance to reduce the potential for increasing erosion and sediment, and to minimize any negative impacts to streams and fish habitat.

Figure 6-3. A non-durable or old rock surface road.

It is readily apparent that hauling during wet weather has exposed the road shown in Figure 6-3, which illustrates the importance of using the appropriate surfacing materials. In this example, the surface was improved with old rock or non-durable rock that was inadequate for the intended use.

Figure 6-4. A durable rock surface road.

Alternatively, Figure 6-4 illustrates a road with an improved surface containing durable rock that has, and will, hold-up to wet-weather hauling.

Road Capacity

It may not always be readily apparent whether a road is capable of withstanding wet-weather hauling. In the case of low-use roads on small private forests, roadside vegetation and lack of maintenance may indicate that a non-durable improved surface was used, which is unable to withstand heavy, wet-weather hauling. It also is possible that the road merely lacks routine maintenance and is fully capable of withstanding heavy loads and wet-weather use.

If the current owner has not used the road for timber harvesting and/or wet-weather hauling, or has no knowledge of previous owners using the road in such a capacity, one may be uncertain of the ability of the road to withstand heavy traffic and/or wet-weather use.

Are these roads capable of wet-weather hauling?

Figure 6-5. Wet-weather hauling example 1.

Figure 6-6. Wet-weather hauling example 2.

Figure 6-7. Wet-weather hauling example 3.

In these instances, a cross-section analysis of the roadway may be needed to accurately determine whether the road can meet the performance standards for its intended use with no negative financial or environmental impacts. **Note:** It is imperative that this evaluation be made prior to road use. Once operations are underway, maintenance and repair costs increase significantly.

In the next two examples, there are two roads with clean, durable rock surfaces spread at various depths. The first road, shown in Figure 6-8, has 10 to 12 inches of rock spread on three lifts of 3 to 4 inches per lift and will be able to withstand wet-weather hauling. The other road, shown in Figure 6-9, has clean, durable rock, but has only one application with a depth of 3 to 4 inches. This road will be capable of supporting light travel by a pickup during the wet season, but will be unable to sustain heavy activity with the onset of wet weather.

Figure 6-8. Improved road surface capable of wet-weather hauling.

Figure 6-9. Improved road surface suitable only for light travel.

Deformation

All roads, regardless of surfacing, deform/depress under vehicle wheel loads and do not return to their original shape (see Figure 6-10). This is how ruts develop on the road surface. The road can quickly develop ruts if the subgrade or surface has been improperly constructed or maintained, or if the road is being used for a purpose that exceeds the capacity of the original construction.

When wet-weather hauling occurs, greater potential exists for damage to the road subgrade and/or surface. The road may fail because the loads simply are too heavy, or failure may occur due to "pumping." When the subgrade soil is compressed from the wheel load, the subgrade becomes saturated and moisture is "pumped" up onto the surface. The water and saturated soil migrates through the more porous rock, contaminating the surface rock and degrading road strength.

Avoiding pumping requires that forest owners prevent standing water by keeping ditches in good operating condition and the road properly surfaced. Some roads may require the use of geotextiles to prevent moisture pumping between the subgrade and road surface (see the "Geotextiles and Their Uses" section). If conditions become too adverse, the road may need to be closed for hauling.

Once pumping occurs, moisture can remain in the road long after the surrounding areas have dried out. In addition, inadequate ditching may allow standing water to saturate the road subgrade and surface.

Figure 6-10. Example of road with poor drainage and resulting deformation.

Normal or marginal road-surface deformation affects only the surface layer. Shallow rutting and/or washboarding is limited to the road surface and does not penetrate into the subgrade. Washboarding is caused by the motion from a vehicle's wheels as they brake or accelerate too rapidly, bouncing on the road surface. This begins to form small corrugations on the surface perpendicular to the direction of travel. Washboarding and minor rutting is considered normal road wear and can be corrected by routine maintenance. Figure 6-11 illustrates the evolution of road-use damage and deformation.

A road may deteriorate to the point where routine maintenance may hide the problem, but the root cause persists. Damage may be hidden when the road surface is reshaped and ruts are smoothed by a grader or backbladed by a bulldozer. This can cause serious problems in the future if the material used to smooth the road surface has pumped saturated soil (mud) into the base or surface layer of the road. Mixing the saturated soil with the surface can cause continual rutting problems, as the road loses strength in the ruts. In severe cases, excavation is required and the base and surface rock must be replaced. In this case, an ounce of prevention is better than a pound of cure.

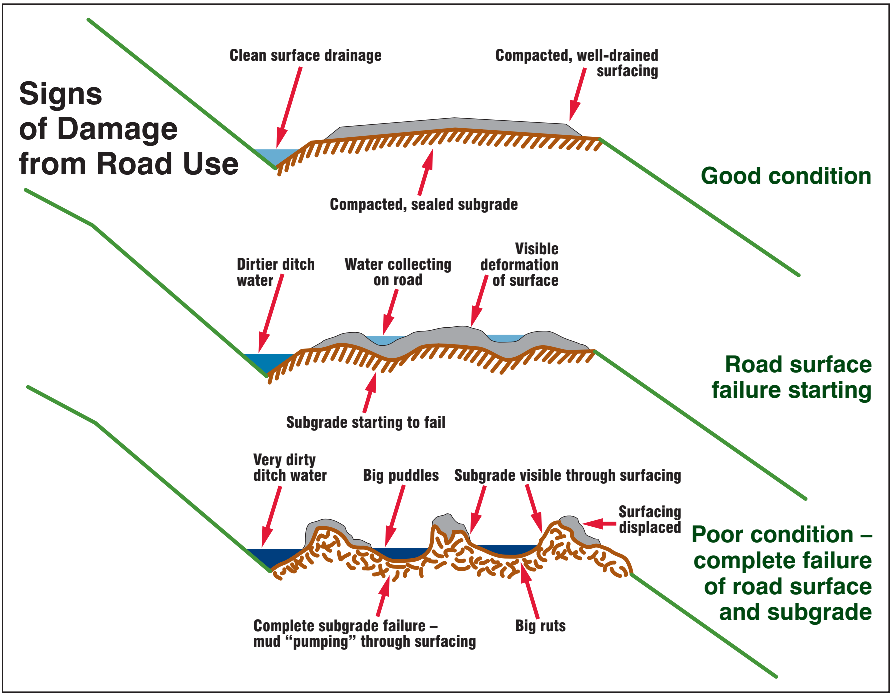


Figure 6-11. Road-use damage signs.

Inadequate Surfacing

Evidence of inadequate surfacing during wet-season use includes:

- a badly rutted and/or uneven road surface;
- subgrade pumping through the gravel; and
- muddy ditch water or road-surface water entering relatively clean streams.

Use of roads during wet season can result in increased stream turbidity and deposition of fine sediment in stream gravel. This occurs when the road surface is too soft to adequately support traffic or when the surfacing material contains excessive fine material. The proximity or direct connection of the road to the stream channel greatly affects the potential for fine sediment to enter stream and wetlands. The durability of the surfacing, traffic volume and subgrade moisture affects the potential for road damage.

Figure 6-12 illustrates a road with inadequate surfacing adjacent to a stream. Careful inspection and maintenance consistent with the weather and durability of the road surface can eliminate or greatly reduce this problem.

Figure 6-12. Example of a road adjacent to a stream with inadequate surfacing.

Following are some of the issues associated with wet-weather hauling:

- Fine sediment from roads can increase stream turbidity and deposition of fines into the stream channel.
- Surfacing that sinks into the subgrade involves extensive and expensive repair.
- Hauling times and expense increase.
- Wet-season traffic on unsurfaced or improperly surfaced roads can devastate surface drainage.
- Even a few loaded trucks on a wet, soft road can result in substantial expense and environmental damage.

During wet-weather hauling, fines can be pumped up onto the road surface and delivered through the road-drainage system into streams, as in Figure 6-13. Also, a poorly surfaced road can be a chronic source of stream sedimentation, as shown in Figure 6-14. Sediment also can be delivered directly into streams through ditch-relief structures, as illustrated in Figure 6-15.

Figure 6-13. Example of delivery of fines from road drainage system.

Figure 6-14. Example of a poorly surfaced road.

Figure 6-15. Example of ditch-relief structure sediment delivery.

Forest owners should recognize and voluntarily address any problems associated with their roads during wet-weather operations. When roads are in close proximity to streams, no level of road maintenance can eliminate 100 percent of the sediment delivery from the road. A certain level of sediment delivery is expected and considered acceptable provided that economically feasible and practicable road maintenance practices have been or are being implemented.

The vast majority of issues involving sediment delivery from a road are caused by a lack of preventive road maintenance and design. Depending on weather and road design and maintenance conditions, there will be times that hauling must cease due to wet weather These stoppages can be minimized by applying durable surfacing or other effective practices in preparation for wet weather.

Forest owners may want to temporarily halt operations during a rain storm, minimizing the rate at which the road surface breaks down, which in turn will decrease the level of delivered sediment. In other cases, some parts of an operation may proceed, even when hauling operations are halted after a snowstorm, such as in Figure 6-16 below.

Some roads have a poor subgrade that, regardless of how much rock is added to the surface, will have potential to deliver sediment to streams during rain events. Poor subgrade is considered a road maintenance weakness.

Figure 6-16. Hauling operations halted after snowstorm. *Photo: Paul Cada*

Following are examples of what can be done to eliminate or greatly reduce the issues involving wet-weather hauling:

- Compact the subgrade and surface to handle the wettest road use conditions.
- Establish criteria regarding when to use and when to stop using a road.
- Use barriers on inactive or unimproved roads.
- Add clean, durable rock to road segments near streams at and near stream crossings and roads in or near floodplains before beginning wet-weather operations.
- Frequently shape roads and maintain drainage during use.

Conditions may reach a point where normal maintenance or repair is not adequate to solve the problem(s). At this point, it is necessary to suspend operations until dry weather returns to avoid spending excessive amounts of time and money. When hauling on unimproved roads, the only solution is to suspend operations. In the case of hauling on improved roads, the problem may be solved, but damage may be so severe and repair so expensive that only the upcoming dry season can alleviate the problem. In the following instances, shown in Figures 6-17 and 6-18, operations should be immediately suspended.

Figure 6-17. Wet-weather hauling on an unimproved surface road.

Figure 6-18. Wet-weather hauling on an improved surface road.

Filtering: Distance from Streams

Install dips, waterbars and/or relief culverts above and away from stream crossings to allow road drainage water to be filtered onto non-compacted and/or vegetated soil before entering the stream. If possible, road-structure systems should be placed within the road 200 feet from the stream so that diverted water travels 50 to 100 feet across the forest floor before entering the stream, as illustrated in Figures 6-19 and 6-20.

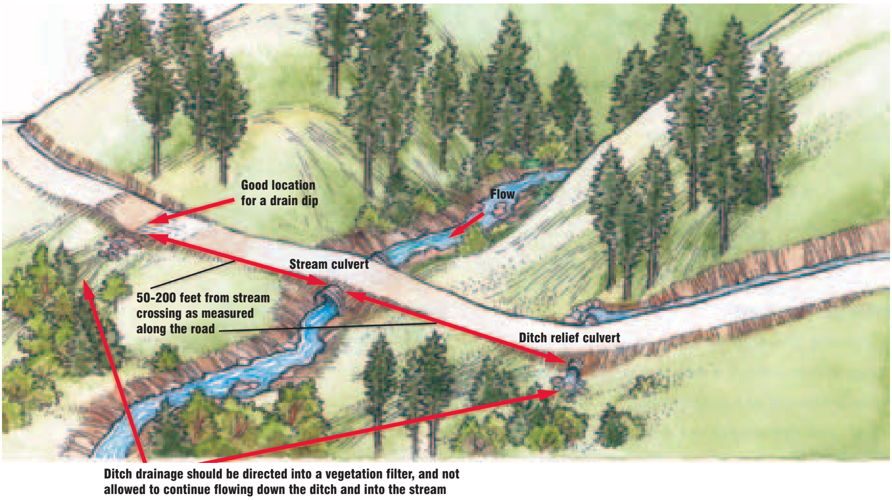


Figure 6-19. Illustration of permanent road structure installation distances.

Figure 6-20. Routing ditch drainage through a filtering of undisturbed vegetation so sediment can be removed before water reaches the stream.

Failure to inspect and maintain roads during wet weather use can lead to chronic turbidity if material is allowed to enter streams. Additional cross-drainage structures above stream crossings may eliminate stream turbidity. There may be instances when steep slopes below the road or a stream adjacent to a road fail to result in acceptable locations for a permanent filtering system. In these instances, temporary barriers may be the only available alternative.

On-site methods of control through seeding or armoring slopes with rock (as in Figure 6-21) and the use of geotextiles may prove successful, but it often is more effective to trap sediment using hay bales (Figure 6-22), settling ponds or sediment barriers. These barriers often are implemented after erosion becomes an issue, but when possible, should be installed before problems arise.

There may be times when environmentally sensitive areas cannot be adequately protected by using only hay bales. Fencing may be used in conjunction with ditching and hay bales to ensure proper filtering. Especially in the case of hay bales, occasional replacement may be necessary to maintain the effectiveness of the system.

Figure 6-21. Use of slope-armoring as a filtering system.

Figure 6-22. Use of hay bales as a filtering system.

Figure 6-23. Example of a road that has become a drainage channel.

If a road has become the drainage channel for water, as in Figure 6-23, measures must be taken to remove the water before extensive damage to the road occurs and/or it flows directly into a stream. If the road has no shape, waterbars will be necessary to move the water to the downside of the road before entering the stream. If the road does have a distinct geometric shape, the solution to adequate drainage may be simple as cutting through a roadside berm.

Cutting through berms to divert water off the road may be inadequate to sufficiently remove sediment before it enters a stream. Hay bales also can be placed along the berm to capture sediment created as a result of road-surface erosion (shown in Figure 6-24). Remember, stop-gap measures involving hay bales and sediment barriers are temporary solutions to the larger problem of direct-source erosion and sedimentation. The issue will persist until the root cause is identified and repaired.

Note: The preferred method of filtering is diverting road-surface drainage water onto stable, non-compacted and/or vegetated soil at least 50 to 100 feet from streams and stream crossings.

Figure 6-24. Use of hay bales for capturing sediment.

Road Closures

If continued wet-weather operations are expected to result in substantial financial and/or environmental impacts, closing the road may be the right decision. It is imperative to ensure that drainage structures are fully functional when temporarily closing a road after seasonal operations. Ideally, the road shape should be crowned, outsloped or insloped, but if no definite road shape exists, or if it is an unimproved road, waterbars should be installed and any berms or ruts should be removed to ensure proper water runoff during the wet season. Please refer also to the previous section "Road Closure and Decommissioning" in Tab 5 for additional considerations.

Several methods can be employed to close a road or deny access. Installing a gate is an excellent method of closing a road because the owner can still gain access and prevent an undesirable situation, as illustrated in Figure 6-25. When using any type of structure to impede access, signs should always be posted forbidding entrance to the property, as shown in Figure 6-26. Gates are available in all sizes and shapes and can be as simple as a highly visible cable stretched across the road or a heavy steel gate embedded in concrete.

Figure 6-25. An example of unwanted access or trespass that can result in an undesirable or harmful outcome.

Figure 6-26. A forest road closure using a gate.
Photo: Colorado State Forest Service

Another method of road closures involves using what nature has provided on the site. Boulders are an effective method of barring access (see Figure 6-27), but heavy equipment is required to move these objects. Deep ditches also may be used, as in Figure 6-28, but require equipment such as a backhoe or bulldozer. Larger, low-quality logs and dirt and/or rocks can be shaped into a berm to block a road. Dirt and rocks should be used with the logs to ensure potential trespassers do not employ a chainsaw to cut through the logs.

Figure 6-27. A road closure using boulders.

Consider permanently closing or vacating roads when:

- the road no longer serves a useful purpose;
- access needs to be eliminated;
- erosion and sedimentation from improper road location needs to be reduced;
- evidence exists of unstable road cuts and fills; and
- the visual quality of road corridors needs to be improved.

Figure 6-28. A road closure using deep ditches.

Road-related landslides are categorized into sidecast failures, fill failures, base failures, cut-slope failures and deep-seated landslides. Sidecast failures sometimes are common on older roads located on steep slopes. Most road repairs deal with reducing hazards related to a sidecast landslide.

If a large landslide occurs, a geotechnical specialist should be consulted prior to beginning any repair operations. In many instances, these landslides cannot be economically stabilized. Ideally, the road can be relocated, or kept open by altering the grade so it conforms to the landslide movement. Fill should not be placed on any actively moving landslides, and runoff from roads should be routed away from these features and all other unstable slopes.

Evidence of the potential for sidecast landslides include:

- nearby landslide scars (Figure 6-29);
- arc-shaped cracks along the outside edge of a road (Figure 6-30);
- fill perched on vegetation or debris;
- cut-slopes that are over 15 feet high; and
- roads located around rock outcroppings.

Figure 6-29. Old landslide scar.

Figure 6-30. Arc-shaped crack on road.

Summary

In some instances, wet-weather hauling on roads with inadequate surfacing and drainage has proved to be extremely costly, both in terms of finances and the environment. Following are points to remember when conducting wet-weather operations on forest roads:

- Use unimproved roads only during periods where damage does not occur.
- Mitigate direct delivery of sediment in runoff water to streams.
- Avoid ditch downcutting.
- Monitor increases in heavy traffic.
- Avoid inadequate depth and/or poor quality road surfacing.
- Install and maintain functional drainage structures.
- Seed and/or mulch eroding soil on cut-and-fill slopes.
- Immediately repair buried or blocked culverts.
- Mitigate fill erosion at the culvert outlet with flumes or rip rap.

Perform these maintenance and repair operations during the dry season to save time, money and the environment. And remember, inspection is a year-round responsibility.

Figure 6-31. An excavator with a hydraulic rock breaker.

Assistance

Colorado State Forest Service District Offices

Following is contact information for the 17 district offices and State Office of the Colorado State Forest Service. This information also is available on the CSFS website at http://csfs.colostate.edu/pages/your-local-forester.html.

District Office	Counties Served	Address	Phone(s)
Alamosa	*Alamosa, Conejos, Costilla, Mineral, Rio Grande, Saguache*	P. O. Box 1137 129A Santa Fe Alamosa, CO 81101-1137	(719) 587-0915 (719) 587-0917 (719) 587-0916 FAX
Boulder	*Boulder, Broomfield, Gilpin*	5625 Ute Highway Longmont, CO 80503-9130	(303) 823-5774 (303) 823-5768 FAX
Cañon City	*Custer, Fremont, Pueblo*	515 McDaniel Blvd. Industrial Park Cañon City, CO 81212-4164	(719) 275-6865 (719) 275-7002 (719) 275-6853 FAX
Durango	*Archuleta, Dolores, La Plata, Montezuma, San Juan*	P. O. Box 7233 Fort Lewis College Campus Durango, CO 81301-3908	(970) 247-5250 (970) 247-5252 FAX
Fort Collins	*Larimer, Weld*	Building #1052 Foothills Campus Fort Collins, CO 80523-5060	(970) 491-8660 (970) 491-8645 FAX
Fort Morgan	*Adams, Kit Carson, Logan, Morgan, Phillips, Sedgwick, Washington, Yuma*	801 East Burlington Fort Morgan, CO 80701-3638	(970) 867-5610 (970) 867-0361
Franktown	*Arapahoe, Douglas, Elbert, Lincoln*	P. O. Box 485 2068 North State Highway 83 Franktown, CO 80116-0485	(303) 660-9625 (303) 688-2919 FAX
Golden	*Clear Creek, Jefferson, [northeast] Park*	1504 Quaker Street Golden, CO 80401-2956	(303) 279-9757 (303) 279-2011 (303) 278-3899 FAX
Granby	*Eagle, Grand, Summit*	P. O. Box 69 201 E Jasper Ave. Granby, CO 80446-0069	(970) 887-3121 (970) 887-3150 FAX
Grand Junction	*Delta, Garfield, Mesa, Pitkin, Rio Blanco*	State Services Building 222 South 6th Street, Room 416 Grand Junction, CO 81501-2771	(970) 248-7325 (970) 248-7317 FAX
Gunnison	*Gunnison, Hinsdale*	P. O. Box 1390 Gunnison, CO 81230-1390	(970) 641-6852 (970) 641-0653 FAX
La Junta	*Baca, Bent, Cheyenne, Crowley, Kiowa, Otero, Prowers*	1904 San Juan Ave. Otero Comm. Coll. Campus La Junta, CO 81050	(719) 383-5780 (719) 383-5787 FAX
La Veta	*Huerfano, Las Animas*	P. O. Box 81 Moore and Poplar Streets La Veta, CO 81055-0081	(719) 742-3588 (719) 742-5502 FAX

District Office	Counties Served	Address	Phone(s)
Montrose	*Montrose, Ouray, San Miguel*	102 Par Place, Suite 3 Montrose, CO 81401-4196	(970) 249-9051 (970) 249-5718 FAX
Salida	*Chaffee, Lake*	7980 West Highway 50 Salida, CO 81201-9571	(719) 539-2579 (719) 539-2570 FAX
State Office	*Not Applicable*	Colorado State University 5060 Campus Delivery 3843 Laporte Ave. Fort Collins, CO 80523-5060	(970) 491-6303 (970) 491-7736 FAX
Steamboat Springs	*Jackson, Moffat, Routt*	P. O. Box 773657 1475 Pine Grove Road, Ste 202A Steamboat Springs, CO 80477-3657	(970) 879-0475 (970) 879-2517 FAX
Woodland Park	*El Paso, Park, Teller*	P. O. Box 9024 113 South Boundary Woodland Park, CO 80866-9024	(719) 687-2951 (719) 687-2921 (719) 687-9584 FAX

Colorado State FOREST SERVICE

For Additional Assistance

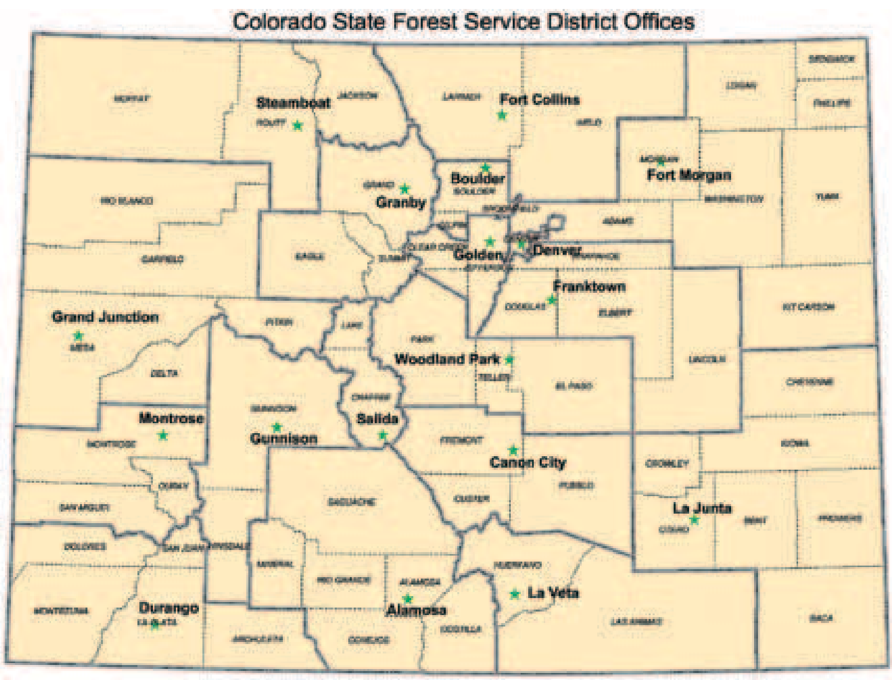
Depending on the desired information, various sources of additional assistance are available to forest owners, including:

Aquatic/Fishery Biologists – for information on the types, needs, time of use and other information about fish in streams near roads.

Consulting Foresters – for information on forestry best management practices, planning and resource requirements, and basic road location and design issues.

Civil and/or Forest Engineers – for structural bridge design and hydraulic analysis of complex culvert installations (baffles, weirs, etc.). Also, for more detailed road location and design issues, which can include county bridge and road departments that may offer assistance.

Geotechnical Engineers and Engineering Geologists – for landslide and sidecast fill-slope stability analysis, waste disposal areas, and bridge and culvert foundations.



Additional References, Sources, and Literature Cited

Various publications exist that may also be of assistance. This list is not inclusive of all available information on state and private forest roads.

Adams, P.W. 1997. Maintaining Woodland Roads. The Woodland Workbook: Oregon State University Extension Service Circular 1139. Oregon State University; Corvallis, OR. 8 pp.

Bolander, Peter and Alan Yamada. 1999. Dust Palliative Selection and Application Guide. Project Report. 9977-1207-SDTDC. USDA Forest Service, San Dimas Technology and Development Center; San Dimas, CA. 20 pp.

Bowers, Steve. (ED.). 2007. Managing Woodland Roads: A Field Handbook. Oregon State University Extension Service – Lane County; Eugene, OR. 108 pp.

Colorado State Forest Service. 1998. Colorado State Forest Service Road Construction Standards. Colorado State Forest Service; Colorado State University; Fort Collins, CO. 11 pp.

Colorado State Forest Service; Colorado Timber Industry Association. 1998. Colorado Forest Stewardship Guidelines. Colorado State Forest Service; Colorado State University; Fort Collins, CO. 33 pp.

Colorado State Forest Service. 2008. Colorado Forestry Best Management Practices: Forest Stewardship Guidelines for Water Quality 2008 Field Audit Report. Colorado State Forest Service; Colorado State University; Fort Collins, CO. 32 pp.

Colorado State Forest Service. 2010. Forestry Best Management Practices. Colorado State Forest Service; Colorado State University; Fort Collins, CO. 28 pp.

Colorado State Forest Service; Colorado Wood Utilization and Marketing Program. 2010. Forest Products Utilization Handbook. Colorado State University Extension Service; Fort Collins, CO. 212 pp.

Corrugated Steel Pipe Institute. 2007. Handbook of Steel Drainage and Highway Construction Products, Second Canadian Edition. American Iron and Steel Institute; Washington, DC. 482 pp.

Darrach, Alfred G., William J. Saurwein, and Clyde E. Hally. 1981. Building Water Pollution Control into Small Private Forest and Ranchland Roads. R6-S&PF-006-1980. USDA Forest Service and Soil Conservation Service; Portland, OR. 168 pp.

Ford-Robertson, F.C. (ED.). 1983. Terminology of Forest Science Technology, Practice, and Products. Society of American Foresters; Bethesda, MD. 370 pp.

Garland, John J. 1991. Road Construction on Woodland Properties. The Woodland Workbook: Oregon State University Extension Service Circular 1135. Oregon State University; Corvallis, OR. 12 pp.

Garland, John J. and D.J. Jackson. 1996. Planning Woodland Roads. The Woodland Workbook: Oregon State University Extension Service Circular 1118. Oregon State University; Corvallis, OR. 8 pp.

Garland, John J. and D.J. Jackson. 1997. Hauling Logs from Woodland Properties. The Woodland Workbook: Oregon State University Extension Service Circular 1140. Oregon State University; Corvallis, OR. 8 pp.

Garland, John J. 2000. Designing Woodland Roads. The Woodland Workbook: Oregon State University Extension Circular 1137. Oregon State University; Corvallis, OR. 28 pp.

Guenther, Keith. 1999. Low Maintenance Roads for Ranch, Fire and Utilities Access. Wildland Solutions Field Guide Series; Brewster, WA. 52 pp.

Haussman, R.F., Emerson W. Pruett. 1978. Permanent Logging Roads For Better Woodlot Management. USDA Forest Service State and Private Forestry; Broomall, PA. 43 pp.

Helms, J.A. (ED.). 1998. Dictionary of Forestry. Society of American Foresters; Bethesda, MD. 210 pp.

Ice, George C., Erik G. Schilling, and Jeff G. Vowell. 2010. Trends for Forestry Best Management Practices Implementation. Journal of Forestry, September. Society of American Foresters; Bethesda, MD. p 267-273.

Keller, Gordon and James Sherar. 2003. Low-Volume Roads Engineering Best Management Practices Field Guide. US Agency for International Development (USAID); Washington, DC. 183 pp.

Kramer, Brian W. 2001. Forest Road Contracting, Construction, and Maintenance for Small Forest Woodland Owners. Research Contribution 35. Oregon State University, College of Forestry, Forest Research Laboratory; Corvallis, OR. 79 pp.

Logan, Robert. 2002. Oregon's Forest Protection Laws: An Illustrated Manual. Oregon Forest Resources Institute; Portland, OR. 160 pp.

Lunsford, Gregory B. and Joe P. Mahoney. 2001. Dust Control on Low Volume Roads: A Review of Techniques and Chemicals Used. Report No. FHWA-LT-01-002. USDOT Federal Highway Administration; Washington, DC. 59 pp.

Lynch, Dennis. (ED.). 2005. Foresters Field Handbook. Colorado State University Extension Service; Ft Collins, CO. 342 pp.

Lecklider, Robert G. and John W. Lund. 1976. Road Design Handbook, 3rd edition. Oregon Institute of Technology; Klamath Falls, OR. 154 pp.

New Mexico State Forestry. 2002. New Mexico Forest Practices Guidelines. State of New Mexico Energy, Minerals, and Natural Resources Forestry Division; Santa Fe, NM. 126 pp.

New Mexico State Soil and Water Conservation Division. 1983. Reducing Erosion from Unpaved Rural Roads in New Mexico. A Guide to Road Construction and Maintenance Practices. State of New Mexico Department of Natural Resources; Santa Fe, NM. 31 pp.

Oregon Department of Forestry. 2003. Wet Weather Road Use. Forest Practices Technical Note Number 9, version 1.0. Salem, OR. 12 pp.

Rocky Mountain Research Station. 2002. Management and Techniques for Riparian Restorations: Roads Field Guides Volume I and II. USDA Forest Service General Technical Report RMR5-GTR-102. 54 pp.

Sessions, John; Jeff Wimer, Forrest Costales, and Michael G. Wing. 2010. Engineering Considerations in Road Assessment for Biomass Operations in Steep Terrain. Western Journal of Applied Forestry 25(3). Society of American Foresters; Bethesda, MD. p 144-153.

Skorseth, Ken and Ali A. Selim. 2000. Gravel Roads Maintenance and Design Manual. South Dakota Local Transportation Assistance Programs. USDOT Federal Highway Administration; Washington, DC. 90 pp.

Swanson, H.N. and D.E. Donnely. 1977. Performance of Culvert Materials in Various Colorado Environments. Report No. CDOH-P&R-R-77-7. Colorado Division of Highways; Denver, CO. 31 pp.

Typar Geotextiles. 2006. Unpaved Roads. Product Engineering Information Pamphlet. Fiberweb; Old Hickory, TN. 11 pp.

USDA Forest Service. 2006. Watershed Conservation Practices Handbook (FSH 2509.25); Chapter 10. USDAFS; Washington, DC. 29 pp.

USDA Forest Service. 1987. Road Preconstruction Handbook (FSH 7709.56); Chapters 2 and 4. USDAFS; Washington, DC. 59 pp.

Wenger, Karl F. 1984. Forestry Handbook, 2nd edition. John Wiley and Sons, Inc. New York, NY. 1335 pp.

Wilson, R.L. 1981. Elementary Forest Surveying and Mapping. OSU Book Stores, Inc.; Corvallis, OR. 183 pp.

Zeedyk, Bill. 2006. A Good Road Lies Easy on the Land…Water Harvesting from Low-Standard Rural Roads. The Quivira Coalition; Santa Fe, NM. 48 pp.

Additional Information and Organizations

Following is a list of additional resources.

Association of Consulting Foresters of America, Inc.

Provide lists of consulting foresters.

312 Montgomery Street, Suite 208
Alexandria, VA 22314
(703) 548-0990
(703) 548-6395 FAX
www.acf-foresters.org

Colorado Division of Wildlife

Aquatic biologists available for fish-bearing stream and fish passage questions.

Headquarters
6060 Broadway
Denver, CO 80216
(303) 297-1192
www.wildlife.state.co.us

Colorado Forestry Association

Colorado Chapter of the National Woodland Owners Association

P.O. Box 270132
Fort Collins, CO 80527
(970) 887-1227
www.coloradoforestry.org

Colorado Timber Industry Association

Trade association and resource for forestry and logging contractors. They also provide Master Logger certification and continuing education to contractors.

P.O. Box 32
Delta, CO 81416
(970) 275-5494
www.coloradotimber.org

Colorado Tree Farmers

Colorado affiliate of the American Tree Farm System. Their mission is to promote the growth of renewable forest resources on private lands while protecting environmental benefits and increasing public understanding of all benefits of productive forestry.

Colorado State Tree Farm Committee
5060 Campus Delivery
Fort Collins, CO 80523-5060
www.treefarmer.com

Natural Resources Conservation Service

Provide consultation and landowner assistance on private lands for a variety of forest roads and soils-related conservation and resource practices, including access roads, channel stabilization, drainage water management, grade stabilization structures, slash treatment, trails and landings, and use exclusion. They also maintain a list of certified and registered Technical Service Providers (TSPs) that can help apply these conservation practices on respective projects.

Colorado State Office
Denver Federal Center
Building 56, Room 2604
P.O. Box 25426
Denver, CO 80225-0426
(720) 544-2810
(720) 544-2962 FAX
www.co.nrcs.usda.gov

Field technical guides
http://efotg.sc.egov.usda.gov//efotg_locator.aspx

Society of American Foresters

Provide lists of Certified Foresters (CFs) and consulting foresters.

5400 Grosvenor Lane
Bethesda, MD 20814-2198
(301) 897-8720
866-897-8720 WATTS
www.safnet.org

US Army Corps of Engineers

For questions regarding the Clean Water Act Section 404 (regulatory program for the disposal of dredged or fill material in the waters or wetlands of the United States) and letters of exemption or permits. Section 404 is regulated by the US Army Corps of Engineers, with oversight by the U.S. Environmental Protection Agency.

Denver Regulatory Office
9307 South Wadsworth Blvd.
Littleton, CO 80128-6901
(303) 979-4120
(303) 979-0602 FAX
www.nwo.usace.army.mil/html/od-tl/introductionto404.html

U.S. Environmental Protection Agency

For further questions regarding the Clean Water Act, including Section 319 (Nonpoint Source Management Program) and further information on Section 404.

www.epa.gov

US Fish and Wildlife Service

Provide biological advice to other federal and state agencies, industry and members of the public concerning the conservation of fish, wildlife, rare plants and their habitats that may be affected by activities. Personnel assess the potential effects of projects to threatened and endangered plant and animal species and migratory birds. They also assess the effects of contaminants on fish and wildlife, and make recommendations on ways to avoid, minimize or mitigate harmful impacts on fish and wildlife resources and their habitats.

Ecological Services, Colorado Field Office
(303) 236-4773
www.fws.gov/mountain-prairie/es/Colorado/index.html

Glossary

Aggregate: Mechanically crushed, angular rock used for forest road surfacing.

Base course: The bottom layer of road-surface rock in a two-layer surfacing system. The base course is the layer between the subgrade and the surface layer of crushed rock.

Centerline: The established center point of a road.

Clearing: Removing standing and dead vegetation within a roadway clearing limits. This is the first step of construction on a forest road.

Clearing limits: The limits of clearing as designated on the ground.

CMP: Corrugated metal pipe, usually constructed of steel or aluminum.

Common material: Soil suitable for fill material.

Compaction: Mechanically compressing soil or rock, resulting in increased density in pounds per cubic foot.

Construction slash: All vegetative material not suitable for timber production, such as tops and limbs of trees, brush and removed stumps.

Control points: Surveyed points on the ground that provide a framework on which further survey operations may be based (Ford-Robertson, 1983). These points are areas where it may or may not be desirable to build a road.

Crowned: A road surface that is sloped from the center of the road to the inside and outside road edges. This is one method of achieving road-surface drainage.

Crushed rock: Rock used for road surfacing that has been mechanically crushed to a specified range of rock- particle sizes.

Culvert: A drainpipe that channels water across and off a road.

Cut-slope: The road cut into the face of the hill.

Downspout: A trough attached to a culvert outlet that carries water beyond the fill-slope to control erosion.

Drain dip: A shallow depression dug across a road to facilitate road-surface drainage without interrupting vehicle passage.

Duff: Accumulated surface litter on the forest floor.

Embankment: Soil, aggregate or rock material placed on a prepared ground surface and constructed to grade. The embankment is the fill material on the downhill side of the road, or, on through-fill sections, the entire road.

End haul: Moving excavated roadway material a distance (usually by dump truck) to the fill site, as opposed to side-casting the cut directly onto the fill.

Energy dissipater: A structure, usually made of rock or logs, that dissipates the energy of water discharged from a culvert.

Environmental impact: An activity that has an effect on the surrounding environment, such as eroded soil from a road silting a nearby stream.

Erosion: The process of dislodging and transporting soil particles by wind, flowing water or rain.

Excavation: Removing earth from an area. Also can refer to the material cut from within the road prism to be used either as fill or end-hauled as waste material.

Filter (or buffer) strip: A strip of land adjacent to a water body; its vegetative cover is used to filter the sediments out of surface runoff water from roads.

Fill: Earth material used to build a structure above natural ground level, as with fill sections on the downhill side of a road.

Fill-slope: Areas on the downhill side of a roadway (or both sides in a through-fill section) that must have excavated material placed on them to build a road section up to grade.

Grubbing: The digging and removal of stumps and roots and removal of duff within the clearing limits of the roadway.

Horizontal curve: A circular curve used to change the horizontal directions, left or right, of a road.

Insloped: A road surface toward the ditched side (or the inside shoulder) of a road. This is one method of achieving road-surface drainage. "Inslope" refers to the amount or degree of steepness of inward sloping.

Landing: A logging site where logs are collected and/or stored.

Lift: A layer of soil or road-surface rock.

Off-tracking: The horizontal distance a vehicle's rear wheels move towards the inside of the road and do not follow the tracks of the front wheels The distance the rear wheel sets on a log truck, tractor-trailer or other vehicle to the inside on a curve. Because of off-tracking, curves will need to be wider than straight sections of road. The tighter the curve, the more a vehicle will off-track.

Outsloped: A road surface sloped to the outside shoulder. In general, an outsloped road needs no ditch because the slope of the road itself sheds runoff water away from the road. "Outslope" refers to the amount or degree of steepness of outward sloping.

Profile view: The side view of an object.

Raveling: The movement of soil or aggregate usually caused by erosion on cut-and-fill slopes.

Relief culvert: A pipe that carries water from road ditches across a road, discharging beyond the fill-slope.

Right-of-way: A general term denoting the privilege to pass over land in some particular line, such as a road right-of-way.

Road grade: The slope of a road surface in the direction of travel, usually expressed in percent (in feet per 100 feet). For example, a 10-precent grade equals a change along the road of 10 feet vertical in 100 feet horizontal.

Road prism: The road geometry between the extreme points of excavation and/or fill.

Roadbed: A road subgrade surface between the subgrade shoulders.

Running surface: The road surface on which vehicle wheels run.

Seasonal road: A road that is used mainly during a specific season, such as a logging road used only during the dry season.

Sidecast: Excavation material that is pushed from a road cut to a fill area. This method generally is used only on gentler slopes and shallower fills.

Slope ratio: The steepness of a slope expressed as a ratio of the slope's horizontal distance to vertical distance with the vertical distance fixed as "1." For example, a 1:1 slope changes 1-foot horizontal to every 1-foot vertical (45 degrees).

Slope stability: Resistance of a natural or artificial slope to movement or failure.

Slough: Material that has eroded and raveled from cut- or fill-slopes.

Slump: Failure of a natural or constructed slope.

Subgrade: The layers of roadbed on which the base or surface course are placed. On an unsurfaced (or unimproved) road, the finished subgrade is the wearing surface (the top layer of the road's surface).

Surface course: The top layer of a road surface.

Switchback: A point on a road where a grade reverses direction on a slope. They are used when two control points cannot be reached by running a maximum design grade in a single direction. (Darrach, et al.; 1981).

Through-cut: A roadway section cut through a ridge; it will have cut-slopes above both sides of the road.

Through-fill: An elevated roadway section with fill-slopes below both sides of the road.

Turnaround: A cleared area on a road or track where vehicles can be turned around. (Ford-Robertson, 1983).

Turnout: A short auxiliary lane on a single-lane road that allows meeting vehicles to pass each other. It usually is designed for ease of access for the unloaded truck so that the loaded truck can proceed.

Twenty-five year flood: A flood/storm event that has a 4-percent (i.e. 1 in 25) probability of occurring annually. This also is called the recurrence/return interval and is based on the probability that the given event will be equaled or exceeded in any given year. The size of this projected flood will determine the dimensions of several components of the road built around streams, such as bridges and culverts.

Vertical curve: A curve that makes a transition between two road grades (such as uphill and downhill grades). Unlike horizontal curves, which are designed as portions of a whole circle, vertical curves are designed with flatter parabolic, or non-circular, curves.

Water bar: A structure installed in the road surface to divert road-surface water off the road. Water bars are constructed from subgrade soil or other materials, such as rubber strips and timber.

Photo: Colorado State Forest Service

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