HANDBOOK FOR FOREST AND RANCH ROADS

A Guide for planning, designing, constructing, reconstructing, maintaining and closing wildland roads

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NOTE: Local, County and State regulations in California cover many of the same subjects presented in this guide. Regulations change quickly, as do the technical methods of reading and the standards for environmental protection. Be sure to follow applicable regulations covering private land road building and related activities for your area. We have provided a general description of the requirements of many (but not all) regulatory agencies, but you will need to be sure that your specific project meets all applicable standards and regulations before you begin work. The information presented in this guide is not an exact "mirror" of California's Forest Practice Rules. However, we have tried to be consistent in terminology, in general content, and in spirit with the goals of the Z'berg-Nejedly Forest Practice Act and California's Forest Practice Rules.

[1] Any errors in the text are those of the authors and not those of the agencies or individuals who provided review of the text. Technical comments and suggestions related to future updates and revisions should be forwarded to Pacific Watershed Associates, P.O. Box 4433, Arcata, CA 95521.

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CHAPTER I: INTRODUCTION

A. Purpose

If you work in a wildland area, own forest or ranch land, or are concerned about our natural resources, this book is for you. It contains guidelines for developing and maintaining a single forest or ranch road or an entire wildland road-access system. It describes how to plan and design a stable road or road network in mountainous lands or gentle valley bottoms, and avoid many of the common pitfalls and environmental/pollution problems for which rural and forest roads are noted. Nearly everything discussed in this manual is aimed at producing efficient, low-cost, low-impact roads that have a minimal effect on the streams of a watershed.

Reading and understanding this manual is not enough. It takes the common-sense, intelligent, practical application of the general principles described here on each "on-the-ground" situation you encounter. Correctly applying these "roading" concepts requires practice and personal judgement. The concepts presented in this handbook are not rules or laws; rather, they are tools which should serve as one of your many sources of information and guidance. The success you achieve will be reflected not only in the stability of your roads, but also in the quality of the water and the health of the streams and watersheds through which they pass.

California's forest and ranch lands provide beauty, clean water, abundant wildlife, fish habitat, recreation, timber and thousands of jobs. This book is dedicated to the wise stewardship of these resources. It describes how we can and should protect our streams, water resources and productive soils, while at the same time provide recreational opportunities and natural resource jobs for our local communities.

B. Contents and organization

This is a practical guide and field manual, and therefore does not cover all topics in the same depth or detail as a textbook. It is designed to be descriptive and informative, yet cover the fundamentals of road planning, design, construction, reconstruction, maintenance and closure. The handbook is organized under these basic topics, and they appear in the general order that they are encountered in the road-building process.

The text of this manual contains both simple informational and instructional material, as well as more detailed discussions of specific practices. For the lay reader, some of the discussions may be too technical, or contain unfamiliar terms and concepts. It is assumed that readers have a basic understanding of road terms (such as fillslope, cutbank, roadbed, stream crossing, etc) and reading practices (such as sidecasting, compacting and endhauling, to name a few). Many of the more technical or uncommon terms have been defined in the text where they first appear, and in the glossary of defined terms included at the end of this book. If you find the descriptions in the text too complex for your needs, a shorter companion volume to this text is available which illuminates the basics of road planning, location, construction and maintenance with a minimum of technical "jargon."

The following summary outlines the chapter contents of this handbook. Within each chapter, some of the more important principles of modem forest and ranch land reading practices have been highlighted in bold print to draw them to your attention.

Chapter 1 discusses how this handbook is organized and serves as an introduction to the concepts of what makes a good road, how a watershed works, and what naturally affects the quality of its water and stream resources. **Chapter 2** describes the need for, and process of, planning for roads. It describes road standards and route planning, using maps and photographs.

Included in **Chapter 3** are discussions of what obstacles to look for during on-the-ground scouting for a road alignment, laying out curves and switchbacks, and a description of the tools that are useful in locating a road in the field. Road design is covered in **Chapter 4,** including road prism and landing design, surface drainage design, and special designs for wet or unstable soils.

Chapter 5 is dedicated to the important topic of road drainage. It includes detailed information on proper surface drainage techniques and structures, ditches, spacing and design of rolling dips, waterbars and culverts, stream crossings, bridges, culvert sizing and placement, and temporary stream crossings.

Chapter 6 covers the construction process, including grubbing and clearing, grading, stream crossing and bridge installation, surfacing, erosion control and spoil disposal. The special but increasingly common activity of road reconstruction is discussed in **Chapter 7**, where the topics covered include road relocation, road redesign, drainage structure upgrading and replacement, and erosion control.

Chapter 8, road maintenance, reviews the topics of road surface maintenance, stream crossing maintenance, maintenance of fills and cuts and winterizing roads. Techniques for indentifying problem culverts and establishing prioritized storm maintenance schedules are also outlined.

Road abandonment and road closure techniques have only recently begun to receive special attention because of their potential long-term effects on water quality. **Chapter 9** describes techniques by which roads that are to be temporarily closed or permanently abandoned can be "erosion-proofed" to prevent subsequent soil loss and to put land back into timber production and other uses.

Finally, the appendices to this handbook contain information on specific topics, such as culvert sizing and curve layout, as well as other sources of information you may find helpful.

C. Watersheds

Wildlands act as the collectors of pure water. Watershed areas collect precipitation and funnel it to downslope and downstream areas through a network of swales and channels carved into the landscape (Figure 1). Some water flows as surface runoff and some enters the soil and groundwater system. Logging, road construction and other activities can disturb the soil and drainage patterns, thereby causing erosion and the release of sediment into stream systems and downstream areas.

Figure 1. *Watersheds in forested and rangeland, areas present a diversity of opportunities and. challenges for water, land and resource management. Roads provide access to areas within a watershed and thoughtful planning, design., construction and. maintenance of road systems are important to protect sensitive streams and aquatic life.*

Streams are classified as **ephemeral** (flowing only during periods of extended rainfall), **intermittent** (flowing during and for a period following rainfall), or **perennial** (flowing most of the year, flow during the summer coming from emerging groundwater). Ephemeral streams may drain water into either intermittent and perennial watercourses. Streams carry both water and sediment to downstream areas, so care must be taken to minimize disturbance to channels and the slopes which drain directly into them. It should be noted that only the largest streams of a watershed are shown on a topographic map, and that many more watercourses, particularly intermittent and ephemeral streams, are likely to be found on the ground. ***Don't rely solely on map information to find and identify streams.***

For forestry operations, the term **"watercourse"** is often used instead of stream. California's Forest Practice Rules (CFPR) describe watercourses as "any well defined channel with distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel or soil... including manmade watercourses." Watercourses are categorized into Class I, Class II, Class III or Class IV. In general. **Class I** watercourses contain fish or provide domestic water supplies. **Class II** watercourses have fish present within 1000 feet downstream or contain habitat for non-fish aquatic species. **Class III** watercourses have no aquatic life present, but show evidence of being capable of sediment transport to downstream locations and **Class IV** are man-made watercourses.

Although not included in the definition of watercourses, roads, road-side ditches, skid trails and landing surfaces can act as man-made drainages which carry water and sediment into natural streams. Care should be taken to disperse surface runoff so these "man-made" watercourses do not impact water quality.

Wetlands are also common watershed features. Wetlands may occur wherever groundwater emerges onto the surface, such as at a spring, a seep, a marsh or a bog, or where water ponds for some time during the year. Some wetlands drain into streams, while others do not. Even when dry, many wetlands can be recognized by the presence of certain water-loving plants. Wetlands should be avoided during road construction activities, as they result in special problems that often require expensive construction techniques and may cause continuing land stability problems. Wetlands require special protective measures and are highly sensitive to disturbance. The California Department of Fish and Game can provide assistance on wetland delineation and protection measures, and can advise you concerning which agency to contact about applicable wetland regulations.

Roads need not threaten the biological productivity and water quality of streams in a watershed if they are properly located and constructed. Poor road building and maintenance practices can cause excess runoff and erosion, leading to sedimentation in downstream areas. Sedimentation can pollute water supplies, increase flooding potential, accelerate stream bank erosion and trigger landsliding. Salmonid eggs laid in stream gravels can become buried and suffocate, fish habitat can be lost, and other aquatic life may be threatened or killed. Riparian vegetation may be impacted, resulting in increased summer water temperatures and loss of food and cover for fish and wildlife.

D. Typical erosion and sedimentation problems caused by roads

Roads are a major source of erosion and sedimentation on most managed forest and ranch lands. Compacted road surfaces increase the rate of runoff, and road cuts intercept and bring groundwater to the surface. Ditches concentrate storm runoff and can transport sediment to nearby stream channels.

Figure 2. *This stream crossing "washed out" (eroded) when the culvert plugged and streamflow scoured through the road road fill. Sediment was delivered directly to the stream system as the fill eroded. Stream crossings and culverts need to be properly designed and maintained to minimize the potential for such failures.*

Culverted stream crossings can plug, causing fill wash outs (Figure 2) or gullies where the diverted streamflow runs down nearby roads and hillslopes (Figure 3).

Figure3. *When a stream crossing culvert plugs, or its capacity is exceeded, flood/low can either build up and/low over the road, washing out the stream crossing/ill, or it can be diverted down the adjacent road or roadside ditch, creating a gully on the road and adjacent hillslope. Diverted flow from this plugged culvert has created a large gully in the down-road ditch. Note scale located at plugged culvert inlet. Road prism is to the right.*

Roads built on steep or unstable slopes may trigger landsliding which deposits sediment in stream channels (Figure 4). Filling and sidecasting increases slope weight, road cuts remove slope support, and construction can alter groundwater pressures, all of which may trigger landsliding. Unstable road or landing sidecast materials can fail, often many years after they were put on steep hillslopes. Lack of inspection and maintenance of drainage structures and unstable road fills along old, abandoned roads can also result in soil movement and sediment delivery to stream channels.

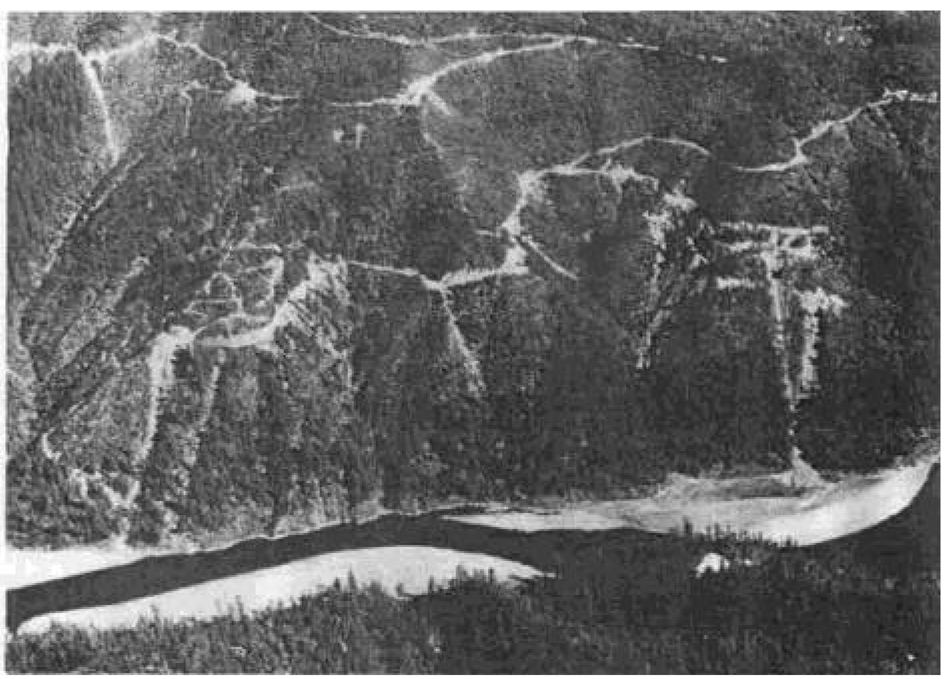


Figure 4. *Sidecast road construction on steep or unstable stream-side slopes and canyons has a high potential/or causing landslides which deliver sediment to downslope stream channels.*

E. Importance of proper planning and construction

Road construction does not have to result in excessive erosion and downstream sedimentation. Proper planning, design and construction techniques used in road location and building, and drainage structure installation, can prevent water quality problems and can significantly extend the useful life of the road. Roads can be planned and located to avoid unstable, credible areas, and stream crossings can be planned, located and built using techniques which minimize the potential for post-construction erosion or slope failure. Good planning, proper location and the use of progressive construction practices can largely avoid the impacts normally associated with road building. Do it right, and youll end up with a low-maintenance, low-impact road. Do it wrong, and you're destined for high maintenance costs and high environmental impacts. The choice is clear.

F. Elements of a stable road

The features described in this section form the building blocks of stable roads. They include elements of the road's physical environment, critical control points (locations of special concern or sensitivity along the alignment), restrictions on road location (legal and physical), how to keep a stable road once it's built, and where to find additional help and information.

1. Physical environment

The physical environment of the road includes such factors as the slope of the land, the types of bedrock and soils through which the road passes, as well as surface and subsurface drainage across the alignment Together, these physical factors determine the best choice for road location in a watershed, as well as the most suitable techniques for constructing a stable, low-maintenance road.

a. Slope of the land: The slope of the land is one of the most important elements that control where and how roads are built. Road building becomes more difficult and expensive as land slopes become steeper. Roads built on steep slopes are also more likely to have erosion and stability problems.

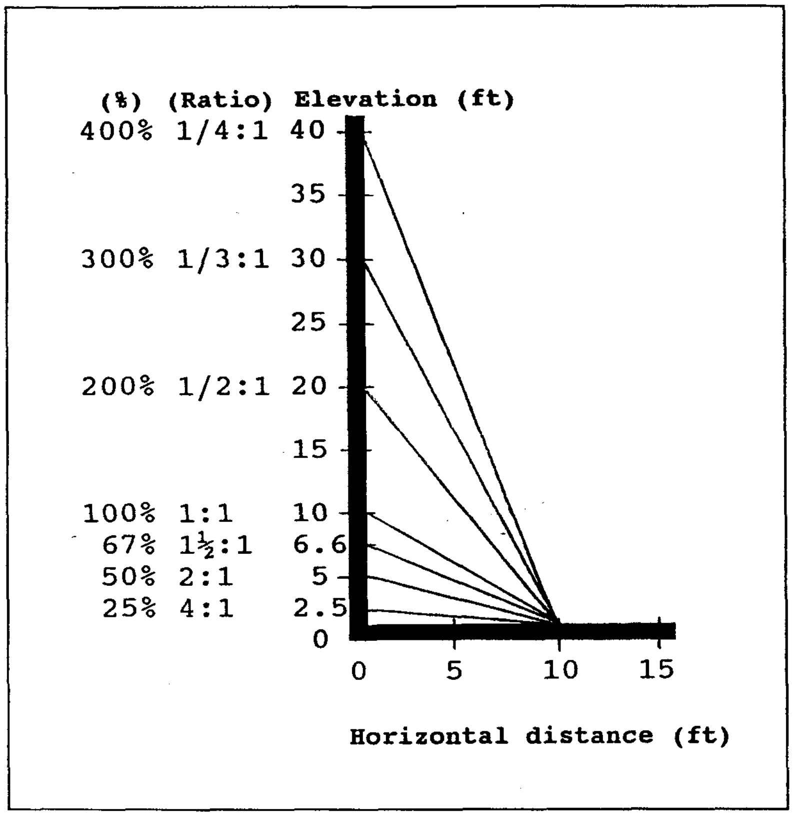
Slope gradient can be expressed in several different ways. The slope of the land is usually expressed in percent, such as "50%". The slope gradient of cut- and fillslopes is often expressed as a ratio, such as 2-to-l. A 2-to-l slope means that for every two feet in the horizontal direction the land surface rises or falls 1 foot in elevation (two feet out for every one foot up or down). A 2-to-l slope is also said to have a gradient of 50 percent (50%). A 100% gradient would correspond to a 1-to-l slope pitch, and a 25% slope has a 4-to-l slope ratio. Less often, slopes are expressed in degrees (e.g. 30°).

Table 1 shows typical land and bank slopes, expressed as horizontal-to-vertical ratio (e.g., 2-to-l, or 2:1), percent (e.g., 50%) and degrees (e.g., 27°), and Figure 5 graphically depicts some of the more commonly expressed slopes. Fillslopes and cutbanks are also described using these slope measurement units.

Table 1. Relationship between ratio, percent and degrees as measures of slope steepness.		
Common Ratios	Percent	Degrees
	5.0	2.5
10:1	10.0	5.7
4:1	25.0	14.0
3:1	33.3	18.4
	35.0	19.0
	45.0	24.2
2:1	50.0	26.6
	65.0	33.0
1½:1	66.7	33.7
	70.0	35.0
	80.0	38.6
	90.0	42.0
1:1	100.0	45.0
½:1	200.0	63.4
¼:1	400.0	76.0

Land slopes can be estimated from the contours on U.S. Geological Survey topographic maps, based on the scale of the map, the spacing between the contour lines and the stated "contour interval" for the map. Table 2 provides the needed data for determining land slope from a standard 1:24,000 scale contour map. Keep in mind, however, that the map shows an average slope between contour lines. In the field, land slope often varies considerably over short distances and is best measured using an instrument called a ***clinometer.*** A pocket-clinometer shows slope steepness, expressed in either degrees or percent, by looking either up or down the slope through the instrument.

Figure 5. Slope diagram graphically shows common cut and fill slope angles, and expresses steepness in both percent and slope ratio.



Roads should not be built directly up a slope that exceeds about 15%, unless it is for a short pitch of less than 500 feet with a road grade not exceeding 20%. This can help prevent serious drainage and surface erosion problems. Most roads traverse across the slope, and it is not difficult to" keep road grades to less than 3%-5%, even where the slope of the land exceeds 50%. Ridges, natural benches and gentle sideslopes far away from stream channels are usually the best places to build roads. Steeper pitches are sometimes required to avoid unstable areas or other obstacles.

Table 2. Land slope (%) as derived from a 1:24,000 scale topographic map

Contour interval of map (ft)	Measured distance (mm) between contours on topographic map (best if averaged along fall line over several contour lines)														
	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	2.0	2.5	3.0	4.0
20	51	42	36	32	28	25	23	21	20	18	17	13	10	8	6
40	102	85	73	64	56	51	46	42	39	36	34	25	20	17	13
80	203	169	145	127	113	102	92	85	78	73	68	51	41	34	25
120	304	254	218	191	169	152	139	127	117	109	102	76	51	61	38

b. Bedrock and soils: The stability and credibility of a road alignment is controlled by the underlying bedrock and soil material. Bedrock composition and the properties of soils vary dramatically along most road routes. Each soil and bedrock type reacts differently to road construction and road drainage.

Some important bedrock properties that influence slope stability and the ease of excavation for road building include rock hardness, direction and inclination of rock layering, amount of natural fracturing, amount of weathering or natural decomposition, and mineral composition. Highly fractured or weathered rocks, or rock layers that slope parallel to the hillside, are likely to result in erosion and stability problems during or after construction. These conditions often lead to high maintenance costs.

A number of soil properties will also influence how easy it is to build a road, how stable the road will be following construction, and how much erosion is likely to occur when the soils are exposed. Such properties include soil depth, credibility, texture, and compactibility. Soil texture is one factor used in determining the credibility or "erosion hazard rating" of a soil, and can be evaluated using simple field tests (Figure 6). The properties of soils in an area can generally be determined from soil survey maps and reports available from the local office of the U.S. Soil Conservation Service or from the California Department of Forestry and Fire Protection.

The responses of soils to road construction and use can often be anticipated from the information in these reports. In practice, where a road is to cross steep slopes, or portions of the route will traverse unstable areas, soil maps should be reviewed and a geologist should be consulted to evaluate the suitability of the site for the planned road building activities.

If soil maps do not exist or are not available, simple tests can be performed in the field to estimate the soil's most important properties. For example. Board of Forestry Technical Rule Addendum #1 for estimating surface erosion hazard rating can be used to estimate the erosional sensitivity of soils the road will pass through. However, this procedure only estimates the soil's susceptibility to surface erosion caused by rainfall and runoff. The likelihood of mass soil movement (landsUding) should be determined in other ways.

c. Drainage: "Drainage," refers both to subsurface drainage (groundwater flow) and surface drainage (runoff).

i. Subsurface drainage: Water held in the soil is called soil water or ground water. If too much water is in the soil (because of seasonal wetness or poor drainage) the weight of vehicles can deform the soil and turn it into mud, with lime form or texture. On a sloping road, the mud can become a safety hazard, the roadbed may be damaged, and sediment can flow into ditches and nearby streams, causing water quality problems.

Some soils are naturally wet and poorly drained, and should be avoided during road building operations. These are often indicated by pools and wet areas on the ground surface, especially during the wet winter months. Such sites can often be recognized during dry summer periods by noting changes in vegetation types. If you are unsure, obtain professional assistance.

Wet areas can sometimes be drained, but unless the source of the emerging ground water is eliminated, wetness may be a continual problem at the site. Once water has emerged onto the ground surface (on the cutbank, in the ditch or on the road surface), it should be directed away from the site and discharged onto a stable area. If the road must pass over a known wet area, modern subsurface drainage techniques can be used to drain the ground beneath the roadbed. Subsurface drainage techniques include the use of gravel-lined "French-drains," with perforated pipes buried in ditches, and other combinations of gravels and overlying filter fabrics. Avoidance is the least expensive and most successful method for preventing subsurface drainage problems, and it is almost always best to re-route the road to avoid natural wet areas.

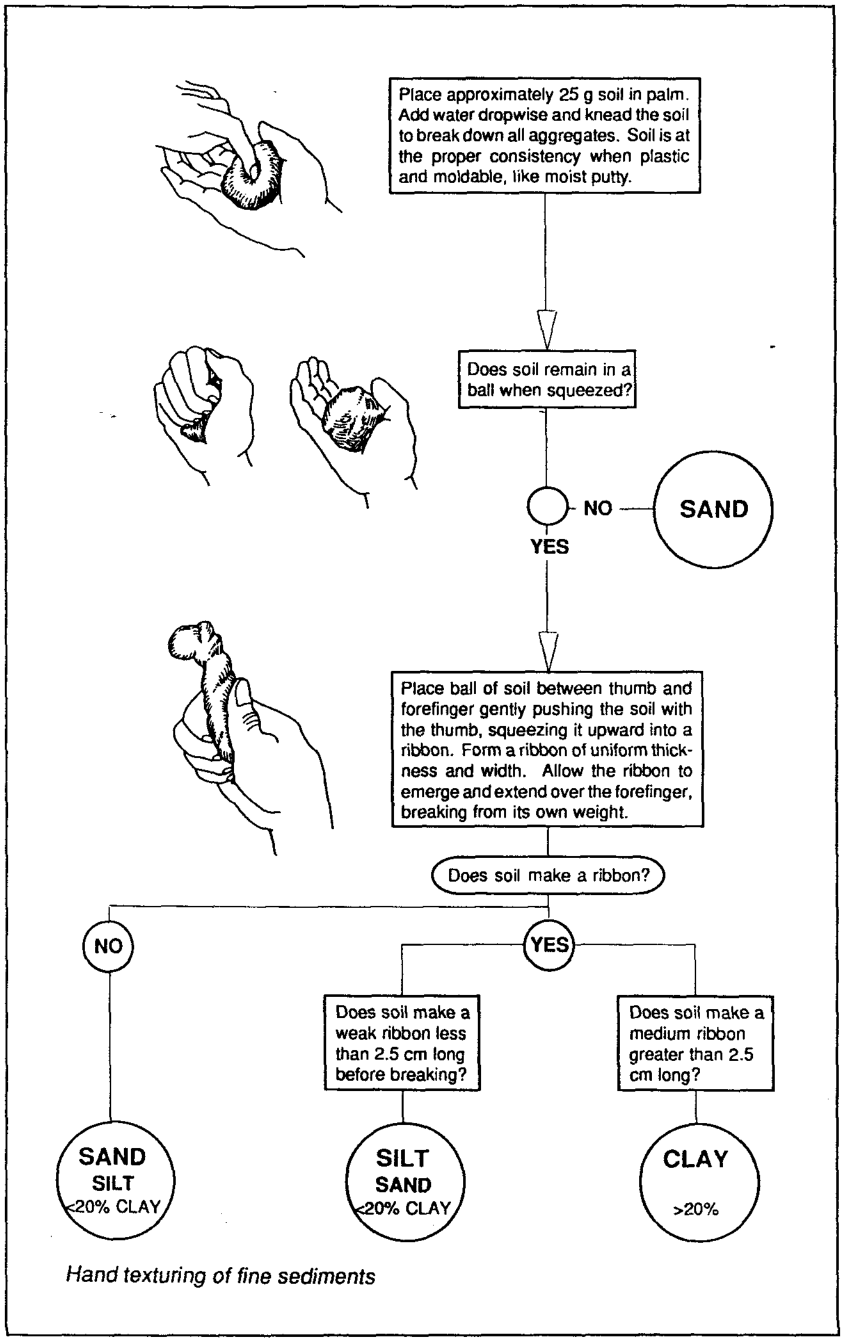


Figure 6. *The texture of fine sediments and soils, an important component used to evaluate soil credibility and erosion hazard, can be estimated using a simple hand-texturing field test (B.C.M.F.. 1991).*

ii. Surface drainage: The key to successful surface drainage is to get the water off the cutslopes, fillslopes and road surface as quickly as is possible, before it has the opportunity to concentrate into a large volume of flow. The two most important rules for accommodating surface runoff are 1) get water off the road *rapidly* so it cannot erode or seep into the roadbed, and 2) get it off the road *often* to avoid large, erosive flows from developing in long, undrained ditches.

A simple method, called the 5-D test, can be used to measure the effectiveness of road drainage systems. This test relies mostly on visual information and analysis of road surface drainage. The 5-D's are:

1. Are all natural **DRAINAGES** conveyed (e.g., carried in dips, fords, culverts or bridges) across the road and released back into their natural channels (this includes both small and large streams and watercourses)?

2. Does the road drainage system actually **DIVERT** water off the road surface?

3. Is drainage quickly **DISCHARGED** from the road?

4. Is the energy of flowing water **DISSIPATED** onto non-erodible material at the point of discharge?

5. Is the **DISTANCE** between structures adequate to prevent erosion of the roadbed?

These five tests apply to all drainage methods, including road outsloping, waterbars, rolling dips, ditch relief culverts, stream culverts and bridges. The first four tests can be conducted by observation; the fifth test can be evaluated by published standards (Table 3) and by field observations for your area.

Table 3. Maximum distance between waterbreaks on roads and trails (feet)[1]

Erosion Hazard Rating (for surface erosion)	Road or Trail Gradient (%)			
	10%, or less	**11-25%**	**26-50%**	**over 50%**
Extremely high	100'	75'	50'	50'
High	150'	100'	75'	50'
Moderate	200'	150'	100'	75'
Low	300'	200'	150'	100'

[1] *from California Forest Practice Rules. This is the* ***maximum distance between waterbars:*** *when in doubt, reduce the spacing. Soils are non-renewable and waterbars are inexpensive.*

The use and correct placement of drainage structures such as culverts, rolling dips, diversion ditches, insloping, outsloping, inboard ditches, ditch relief culverts, waterbars and stream culverts are worth the initial cost of installation. Correction and repair may be 2-10 times more costly than the original installation, and damage to the land and nearby streams may not be correctable.

2. Control Points

The stability of a road and its impact on the environment are often determined by how the road is designed and located around physical points of control in the landscape. Efforts should be made to avoid as many obstacles and stream crossings as is possible when planning and locating a road alignment

a. Obstacles: Obstacles to a stable road include unstable slopes (slumps, debris slides, debris flows (torrents), and earthflows), hard rock outcrops, very steep slopes, highly erodible soils, ponds and lakes, swamps and property boundaries. These features should be precisely located during road reconnaissance since they constitute control points that will influence the final location of the road.

Agreements with adjacent landowners should be arranged when needed to prevent property boundaries from forcing roads to be built in unstable or unsuitable locations that could cause excessive erosion and damage in downslope and downstream areas. In addition, recognition of slope instabilities may sometimes be easy, but the skill and expertise of a trained geologist is often needed to determine the full extent of unstable areas and to choose a suitably stable alternate route which bypasses the obstacle. **In the long run, employing an expert to solve a technical problem is much less expensive than repairing a major road failure.**

b. Stream crossings: Stream crossings are particularly vulnerable to erosion and failure. For this reason, **the number and size of stream crossings that have to be constructed along a new road should be strictly minimized.** The more deeply incised a stream canyon is, the more excavation, soil disturbance and erosion are likely to occur during and after construction of the crossing. Therefore, stream crossings should be located where the channels are least incised, across natural benches, and where sideslopes are gentle and stable. In addition, stream crossings should be built at right angles to the stream channel, and, where possible, streams requiring a 48", or larger, diameter culvert or large volumes of fill should be bridged.

The use of prepared crossings is required wherever roads must cross a stream or watercourse. They may be permanent, including a culverted fill crossing, a bridge or a ford, or they may be temporary, such as a temporary culverted fill or a log crossing, that needs to be removed before the beginning of the following winter period (generally considered as beginning on October 15). All forest-land stream crossings that are to remain in place for one (1) or more winter periods must be designed to pass at least the 50-year storm flood flow. Crossings on older forest roads that need reconstruction must also be designed to current 50-year flood standards (methods for estimating the 50-year flood flow for a stream are included in Chapter 5 and in Appendix A). These standards are appropriate for all wildland roads, including forest and ranch land road systems.

Stream crossing installations often require a California Department of Fish and Game (CDFG) 1603 permit before any in-stream work can be undertaken. Many Class I, II and III watercourses not shown on the topographic maps will need 1603 permits, and all watercourses that are identified on maps, on photos or during field reconnaissance will need properly planned and designed stream crossing installations. If you need assistance, ask the Department of Fish and Game for their advice in preparing a stable stream crossing.

Some stream crossings require extra careful design to accommodate fish passage. These will require consultation with CDFG experts, to determine crossing type (ford, bridge, pipe arch or plate arch culvert or full round culvert), culvert length, the need for baffles, inlet and outlet location, acceptable culvert grade, resting and jump pools, and water depth. Preparing and installing the proper crossing in the first place is also much less expensive than having to modify a structure already in-place.

c. Road grade: The slope of the road is called "road grade." This is not the same as the slope of the land. Road grade is typically expressed in percent (%). A road that rises or falls 10 feet for every 100 feet of its length has a grade of 10%.

Steeper roads are more likely to suffer from erosion and vehicle damage if used when wet, and this leads to increased safety hazards compared to low gradient roads. Where possible, new road alignments should use grades of 3% to 5%, or less. According to the California Forest Practice

Rules, grades should be kept below 10% (try for a 7% maximum) except for short pitches of 500 feet or less where road grades may go up to 20%. These steeper road grades should be paved or rock surfaced and drained frequently if they are to be used during the wet winter months.

3. Other limitations on road construction and location

A number of physical limitations on road location have already be discussed, including obstacles and stream crossings. But other factors may also limit when and where a road can be built

a. Seasonal construction limitations: California's climate is generally one of wet winters and dry summers. The extremes of wet and dry limit the dme of year when construction activities can safely take place. However, there are a number of planning and reconnaissance activities that can, and should, take place during wet periods. Indeed, winter is the best period for field reconnaissance and to identify springs, seeps and small streams that might not be visible during dry periods.

Generally, construction and reconstruction activities should be dmed to minimize soil erosion, to give vegetation dme to take hold before heavy winter rainfall begins, and so heavy equipment will not have to work on wet soils. Late spring through middle summer is the best period for heavy equipment work in many locations. Some moisture is required and desirable for adequate compaction of fill materials, but road construction should not begin before the soil has had time to drain and dry.

Table 4 outlines activities that can be safely conducted during various times of the year. In some years there are extended dry periods during the winter months when some heavy equipment work can be performed. However, California Forest Practice Regulations require that erosion control work be kept current, that a winter period operating plan be prepared and filed (if necessary) to guide winter operations, and that work be immediately shut down ***before*** conditions begin to affect water quality.

Table 4. Timing of road planning and construction activities.

Season	Planning and design	Field Layout	Construction and re-construction	Inspection and Maintenance	Closure
Winter	+[1]	+	No	+	No
Spring	+	+	V (late)	+	-
Summer	+	-	+	+	+
Fall	+	-	V (early)	+	+

[1] *Key to symbols: + = good or excellent season/or this activity. "\/ = OK or good time to perform this work. - = not a very good season for this type of work. NO = this is not a good time for construction or closure -work using heavy equipment, unless there is an extended dry period. Each season has periods when work can be undertaken. Winter equipment work, if undertaken, should be planned and conducted carefully, with erosion control work kept up-to-date.*

b. Buffer strips and stream or watercourse and lake protection zones (SPZ; WLPZ): A sufficient buffer or filter strip of undisturbed vegetation should be left between road building and road maintenance activities and nearby streams. Road surface drainage should be sent through a filtering area with enough ground cover to catch any sediment coming from road runoff. Filter strips should be retained even for Class III watercourses and ephemeral streams that may not be flowing at the dme of road construction or maintenance. **Streambeds do not *make* good roads and should not be used for that purpose.**

Table 5 lists recommended minimum filter or buffer strip widths for protecting water quality, but these distances may have to be modified depending on vegetation cover and soil conditions. Where there is inadequate roadside vegetation, physical barriers (logs, brush, ditches, etc.) or small sediment retention structures/basins may be added to trap some of the sediment coming off the road surface or fillslopes. For example, the filtering effectiveness of buffer strips can be dramatically improved if slash is placed at the base of fillslopes along the road alignment These structures are called **filter windrows.** Inboard ditches and ditch relief culverts should be discharged onto vegetated slopes and ***never*** into natural stream channels or-watercourses.

Table 5. Recommended minimum widths for buffer/filter strips between wildland roads and streams[1]

Slope of land between road and stream (%)	Minimum width of vegetated filter or buffer strip (ft)
0	50
10	90
20	130
30	170
40	210
50	250
60	290
70	330

[1] *USDA, 1978*

c. Ordinances: County, state and federal ordinances regulate many aspects of road construction, reconstruction and maintenance. Some examples of these are listed below.

i. County - Department of Public Works and/or Building Departments often have grading ordinances that may apply in your area. These ordinances describe how private roads may be constructed and how these roads may connect with existing public roads. Permits may be required, and County Planning Departments may also want to review proposed roads that are being constructed for large and small lot splits and subdivisions, even in rural areas.

ii. State - State regulatory agencies with jurisdiction on road construction and related activities include the Department of Transportation, the Department of Fish and Game, the Department of Forestry and Fire Protection, and the Water Resources Control Board. Several other agencies have special jurisdiction. The California Department of Transportation controls private road connections with state maintained roads and highways. An application fee and bond or deposit may be required for this type of work. You should also check with the Coastal Commission when planning a road within the Coastal Zone. For new roads, archaeological clearance may be needed in areas where records show prehistoric activity or habitation. For developing rock pits and borrow sites over one acre in size, or exceeding 1000 cubic yards of overburden or rock material, the Department of Conservation should be consulted regarding development and reclamation requirements of California's Surface Mining and Reclamation Act (SMARA).

The Department of Fish and Game will need to review all road construction, road reconstruction or road removal jobs where the bed or bank of a stream or lake will be altered. This specifically applies to proposed stream crossings. A formal notification needs to be made to the Department, submitted on Form 1603, describing the proposed work and including an application fee (see Appendix B). The Department has 30 days to respond to the application and may propose mitigations and/or ask for a field review of the site. Most 1603 applications take about three weeks to clear before operations can begin, so paper-work needs to be submitted ahead of time. Check with the local warden to file a 1603 application and/or to set up a field inspection.

To build or rebuild a road for commercial harvesting of trees, firewood or other forest products, a licensed forester needs to file a timber harvesting plan (THP) with the Department of Forestry and Fire Protection. This includes any commercial timber or other saleable wood products from road building or reconstruction work. Specific regulations must be followed for planning, designing, constructing and maintaining these logging roads (Appendix C). Fire-safe road standards have also been developed for rural subdivision roads that require CDF review prior to construction.

The State Water Resources Control Board and the Regional Water Quality Control Board with jurisdiction in your area administer and enforce provisions of California's Porter-Cologne Water Quality Act, as well as the Federal Clean Water Act. Whenever water quality and the beneficial uses of water could be affected, these agencies need to be consulted. Sediment entering streams and watercourses is a serious pollutant and road construction, reconstruction and maintenance activities, if not performed properly and with care, can cause downstream pollution. Clean-up and correction actions ordered by the Board can be costly and cause significant delay, so it is always best to follow practices which are protective of water quality.

4. Keeping a stable road

Building a road should be viewed as a long-term commitment of both resources (cash and equipment) and personnel. If you are unable to make that commitment, then the road either should not be constructed, or it should be built as a temporary road with drainage structures that are removed after use. Many dead-end spur roads built during timber harvesting activities can and should be designated as temporary. If and when they need to be rebuilt in the future, stream crossings can be reconstructed and the road regraded.

A road built with drainage structures and stream crossings needs to be maintained during the winter period (as storms occur), during the summer period (as it is being used), and preceding each winter period (to prepare the road for winter). Periodic and storm maintenance inspections and activities need to be performed frequently and regularly during the first several rainy seasons as the road "settles in" and stabilizes. Each year that follows, the road and its drainage structures should be regularly checked'and, when necessary, repaired.

When the need for a road diminishes, it is not sufficient to close the road by simply abandoning it or by putting up barricades or a gate. If a road is not going to be maintained for one or more seasons, it needs to be proactively abandoned or "erosion-proofed." This is done by excavating stream crossings and removing culverts and by excavating potentially unstable fill material that might fail and deliver sediment to local stream channels during winter storms.

5. Where to find help...

Many people and references are available to help with development of wise decisions on planning, designing, locating, constructing, reconstructing, and proactively abandoning wildland roads. Table 6 lists some of the sources you can contact for guidance on plans for where, how and when to build a road. Don't hesitate to seek advice and assistance from other knowledgeable professionals with experience in your area.

Table 6. Sources of information for planning, constructing, maintaining and abandoning small private roads (modified from S.C.S. 1983).									
Suggested source	**Aerial photos**	**Weather reports**	**Vegetation**	**Permits**	**Technical assistance**	**Maps and Literature**			
						Soils	**Geology**	**Topo-graphy**	**Roads**
Federal…									
Soil Cons. Service	X	X	X		X	X	X	X	X
Forest Service	X	X	X			X	X		
Bureau of Land Mgt.	X		X			X			
Extension Service	X	X	X		X	X	X	X	X
Geological Survey	X						X	X	
ASCS	X								
NOAA		X							
State...									
Dept. of Forestry	X	X	X	X	X	X	X	X	X
Div. of Mines and Geology	X				X		X	X	
Department of Transportation				X					X
Department of Fish and Game				X	X				
Reg. Water Quality Control Boards				X	X				

Table 6. (CONTINUED)

Suggested source	**Aerial photos**	**Weather reports**	**Vegetation**	**Permits**	**Technical assistance**	**Maps and Literature**			
						Soils	**Geology**	**Topo-graphy**	**Roads**
Universities (Depts. of Forestry, Geology and Engineering)		X	X		X	X	X	X	
University libraries			X			X	X	X	X
County...									
Public Works, Road or Building Depts.	X			X	X?				X
Timber Tax or Nat. Resource Depts.	X								
Planning Dept.	X			X					
County library			X?			X	X	X	
City & local...									
City library			X?			X	X	X	
Government				X					
Private...									
Consultants (forestry, geology, engineering, wildlife, etc.)	X		X		X	X	X	X	X
Outdoor stores								X	

CHAPTER II: PLANNING

A. Introduction to road planning

Good planning can minimize the impact of a road on the environment and provide low-maintenance, low-cost access for landowners. It will pay many times over to sit down and seriously plan for the road and road network before making irreversible decisions that cost extra money, waste time later and damage the environment

Two basic tenets of road planning should be followed. **First, minimize the number of roads constructed in a watershed through basin-wide planning.** If you don't own the entire watershed, consider meeting with other landowners to see how road network planning can benefit everyone by saving money and causing the least impact. Most landowners want to cause as little disturbance as is possible and to minimize costs. There is great economic and environmental benefit to developing a coordinated road plan and reducing road construction in a watershed. Roads should be minimized because they remove land from production and often cause erosion.

Second, existing roads should be used wherever possible, unless using such roads would cause more severe erosion problems than building a new alignment elsewhere. Existing roads might require some rebuilding or upgrading, but using them is usually much less expensive than new construction. Sometimes, because of property lines that divide ownerships, roads have been built close together on adjacent properties. Cooperative use of existing roads can prevent this kind of duplicate and unnecessary construction in the future.

Efforts should be made to develop easements or agreements that allow mutual use of roads on or near property boundaries. Written and recorded rights-of-way mutually benefit all parties concerned. Such agreements should define the road location, ingress and egress routes, road width, levels of use, maintenance responsibilities, monetary considerations, and any other pertinent points. A survey, properly recorded, may be needed to clearly identify the boundary line. It is suggested that an experienced local attorney be consulted to ensure that all legal and liability requirements have been addressed.

B. Need for a road

Two of the most important steps in planning for a road are 1) determining whether or not the road is actually needed and 2) deciding what standard of road is called for. Ask yourself these questions:

What will the road be used for? Will it be used for residential access, access for grazing or farming, timber hauling, fire control, or for recreation? What kind and size of vehicles or log yarding equipment will be used?

How often and when will the road be used? Is it a one-time use (e.g., for timber removal) or daily use (e.g. for residential access)? How fast do you expect to travel? Is it only to be used during the summer or will you need to use it during wet winter months (i.e., does it need to be an all-weather road)?

Is there an existing road, either on your property or on an adjacent property, that could be used or rebuilt? If the road is being built for timber removal, can an alternate harvesting or yarding method be selected that would either shorten the length of new road or eliminate the need for a new road altogether?

A sound, thoughtful review of the present and future needs for this road will assure that it will accommodate your needs. It is frustrating, and potentially costly, to build a road that cannot accommodate all the needed uses. At the same time, both forest and ranch roads should be built to the minimum standard necessary to accommodate all reasonably anticipated uses and equipment

C. Road size and standards

After deciding why a road is needed, you can determine the minimum size or standard that is appropriate to meet your requirements. Table 7 provides suggested minimum standards for single lane, packed gravel surface and dirt roads with traffic of less than 100 vehicles per day.

Horizontal curves occur where the road goes around a ridge, watercourse or other obstacle, and vertical curves are those where the road goes over the crest of a hill. Both kinds of curves require a minimum length of visibility at a given driving speed to assure safe stopping distances for trucks and other vehicles.

It is also important to provide passing lanes and turnouts on narrow, single lane roads, and turnarounds are needed at the end of all dead-end roads. Turnouts should generally be located so you can see from one to the next, and so oncoming traffic can safely pass without vehicles ever having to back up.

In some situations, long, straight roads may encourage excessive speeds. To discourage unsafe driving speeds, straight sections of road can be limited to 400 feet, or less. The road should be contoured to the landscape to minimize cuts and fills. Rolling dips, used for surface road drainage, also help keep travel speeds at a safe level.

Other considerations may also dictate road size. For example, in erodible, unstable or steep terrain, small narrow roads are often preferred because of their lower environmental impact. Spur roads and other low volume roads are often narrower and of lower standard than trunk roads that service large areas or serve as major connecting links in the road network.

Table 7. Suggested minimum standards for single lane gravel and dirt roads[1]				
Standards		**Design speed (MPH)**		
		10	**15**	**20**
Speed range (MPH)		5-15	10-20	15-25
Stopping distance (ft)		40	68	100
Horizontal curve radius (ft)	No sight obstruction	55	110	200
	obstructions 9 ft from road edge	100	300	600
Vertical curve length (ft)		200	200	200
Stopping distance for approaching vehicles, controlled by horizontal and vertical curves (ft)"		100	170	250
Travelling surface width (ft)		10	12	12
Road grade for heavy trucks (%)	Maximum sustained	7	4	3
	Minimum sustained	2	2	2
Maximum pitch (%) (<500 feet)		18	18	18

[1] *from USDA-SCS (1981)*
[2] *2½ times single vehicle stopping distance*

All other conditions being favorable, financial considerations and planned uses may play large roles in determining road standard and size. Costs are directly proportional to the standard of the road, and high standard roads are usually built where economic returns from land management (such as logging or mining) can pay for the added improvements, or where planned uses require high standard roads (e.g., for wet weather access to residential property).

For forest roads, standards and size may also be dictated by harvesting and yarding equipment needs, as well as the season of use. Other types of land use have their own special or unique requirements for standards. Features such as paving or rock surfacing, dual lanes, and oversized drainage structures can all add substantially to construction costs. If these features are not needed, given the planned use of the road and requirements for environmental protection, they should not be built into the project.

Road classification also indirectly affects road standard. Forest and ranch roads are often divided into classes called permanent, seasonal and temporary, in generally decreasing order of road standard and size. **Permanent roads** form the core of the all-season road network, and are surfaced to allow winter uses, such as log hauling (Figure 7). Permanent roads have watercourse crossings designed to accommodate at least a 50-year flood flow at all streams. **Seasonal roads** are a part of the permanent road network with drainage structures (or fords) designed to pass the 50-year flow, but they may not be of sufficient standard for heavy, wet-weather use or hauling. Both permanent and seasonal roads require regular, seasonal and storm period inspection and maintenance (Figure 8).

***Figure 7**. This well built permanent road is designed/or year-around use. It is contoured to the natural topography, has no inboard ditch, is slightly outsloped, has no outside berm, is occasionally rolled to provide continuous surface drainage and is rock surfaced for wet-weather traffic. This self-maintaining design will provide years of uninterrupted use.*

***Figure** 8. Seasonal roads are built to the same specifications as permanent roads, but are not surfaced for all-weather traffic. They typically provide summer or dry period access to watershed areas. The potentially credible road surface may be waterbarred before each winter (not shown), or outsloped with rolling dips to provide for rapid drainage of surface runoff.*

Temporary roads are lower standard roads with a surface adequate for use during the dry periods and drainage structures adequate for flows during the anticipated period of use, but that are removed before the beginning of the winter period (Figure 9). Temporary roads may remain in-place for several years before they are removed only if their drainage structures are designed to accommodate the 50-year flood event. Upon abandonment, all drainage structures and stream crossing fills are removed, and the road surface is permanently drained using outsloping rolling dips, waterbars and ditches.

Figure 9. Temporary roads are often spur routes constructed off permanent or seasonal roads that provide short-term access to watershed areas. They are usually outsloped, unsurfaced and used only during dry soil conditions. All stream crossings need to be physically excavated and removed upon the completion of operations or prior to the onset of the winter period (October 15 for forestry roads). In forested areas, the road bed can be planted with trees to return the site to productivity.

D. Road system layout

In forest and ranch road planning, the concepts "less is best" and "avoid the worst" generally describe the most economical and environmentally sound approach to planning for road building and road system layout. Some of these important concepts are listed below:

1. Minimize total road miles in your watershed,
2. Minimize new road construction by using existing roads,
3. Minimize construction of permanent and seasonal roads by using these standards only when absolutely necessary; use temporary roads to minimize long-term maintenance and reconstruction costs and reduce environmental damage,
4. Strictly minimize the number of watercourse crossings,
5. Minimize cuts, fills and vegetation clearing by contouring roads across the landscape,
6. Minimize road work near the WLPZ, and on unstable areas, inner gorges and steep slopes,
7. Minimize road width,
8. Minimize road gradient,
9. Minimize the concentration of runoff on and from the new road, and
10. Avoid problem areas and serious obstacles, when possible.

Road system layout is influenced by many factors, including topography, property lines, obstacles (rock outcrops, unstable areas, etc), and proposed landuse activities. Controls on the location of a road include both natural features and man-made elements (Table 8).

Table 8. Some man-made controls which affect road location[1]	
Control	**Comment**
Legal	Boundary lines limit the location of a road. Talk with adjacent landowners and work out written right-of-way agreements to share roads and reduce road construction.
Specific location	The beginning and ending points of a road are often fixed. These represent major controls.
Safety	Each class of road and level of use have specific safety requirements. Common sense should be applied in setting speed, grades, curve radius, sight distance, and turnouts.
Pollution control	Roads should avoid problem areas. Allow ample room to trap sediment in a buffer before it reaches a stream. Do not allow any direct discharge points where road runoff flows directly into the stream. Avoid flood plains, landslides, credible soils, etc., as well as slopes over 40% wherever possible.
Design elements	Physical limits for curve radius, road grade, pitch grade, stopping distance and separation from streams are set by you! Design to reduce maintenance costs and pollution potential.
Migrating fish	Observe and maintain substantial buffers. Know what species use your streams, their habitat requirements, the susceptible periods of their life cycle, and their environmental tolerance limits. Permits may be needed from the Department of Fish and Game.
Approach road permits	Issued by California Department of Transportation or the County for roads connecting to public highways. Locations for intersections may be restricted.

[1]*modified from USD A-SCS(1981)*

1. Harvesting and yarding techniques: For timberland owners, road systems are often planned around the preferred method of timber harvesting and yarding for the terrain. Downhill tractor skidding, a common yarding technique in the past, require roads to be built in lower hillslope positions where slopes are often steeper, soils less stable and streams more incised into the landscape. These conditions can lead to greater erosion and soil loss from road construction, and higher long-term maintenance costs. Cable yarding allows most roads to be build near ridges and in upper hillslope areas where environmental impacts may be significantly reduced. Integrated planning for modem yarding techniques and road location and design will achieve the most economically and environmentally sound road system.

2. Road construction versus reconstruction: In the last 50 years, tens of thousands of miles of road have been constructed on private forest and ranch lands in California. Most of these roads were built to accommodate timber harvesting, ranching and rural development. Many of these roads are now abandoned and grown over with vegetation. Some were built in locations which would not be acceptable for new road construction today. As these areas are re-entered for additional logging and land use, decisions must be made as to whether or not it is better to use the existing abandoned road system, or to build a new road network in a better location using state-of-the-art techniques (Figure 10).

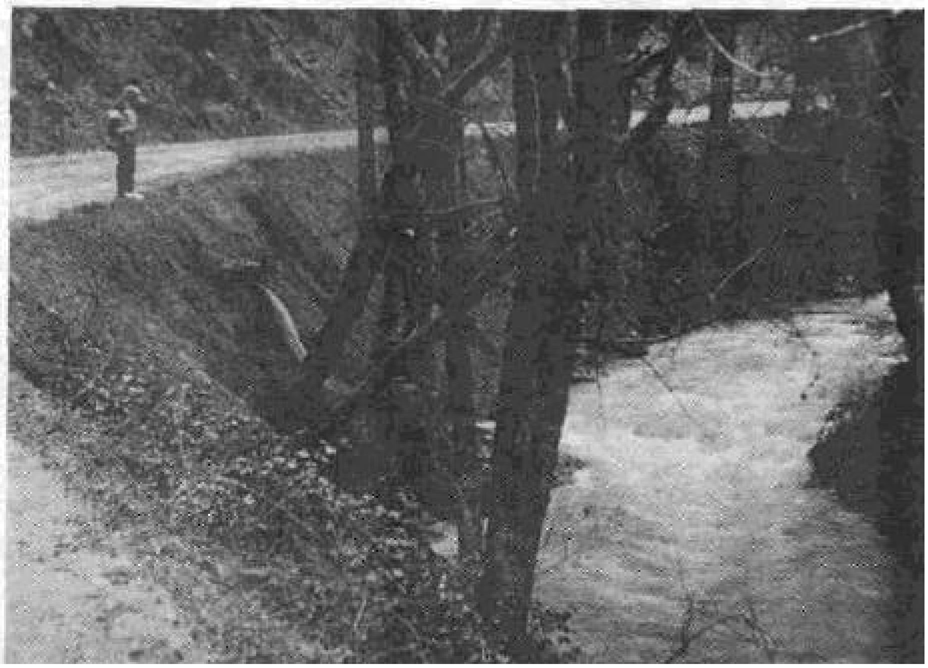


***Figure 10.** Because of our increased awareness of the potential impacts to streams in a watershed, some roads which were built in the past would probably not be built in the same locations today. In this example, a side-cast-constructed road was built alongside a large, fish-bearing stream and ditch relief culverts still discharge muddy road runoff into the channel during storms.*

The answer lies in considering both economics and environmental impacts. In many instances, reconstruction can be viewed as an opportunity to cost-effectively improve watershed conditions and reduce the threat of long-term erosion, while providing the opportunity to economically access a previously harvested or managed area.

For example, in a final forest re-entry it is often possible to temporarily open an old road for forestry activities, and then to systematically and permanently close it upon completion of operations. This "road closure" would involve removing drainage structures, stream crossing fills, and unstable sidecast, and permanently draining and planting the road surface. In this way the old road can be **"erosion-proofed"** against future storm damage, and returned to forest or ranch-land production. At the same time, an economical temporary access to the site has been developed for at least one summer's work. Proactively planning for this option, where it can be used, is often both economically and environmentally advantageous.

In other circumstances, an old road system may be so deteriorated that only small portions of it can be safely used without causing extensive erosion. In this case, new roads may need to be planned and located at more stable, suitable hillslope locations. As this may be the only chance for rehabilitation work, efforts should be made to correct as many erosion problems along the old road network as is possible when the logging operation is being conducted.

Finally, an old, abandoned road system may be located in an environmentally suitable location, but because it has been abandoned for a number of years it is now overgrown with vegetation. In this case, reconstruction may cost significantly less than new construction, and result in little erosion. Sections of the reconstructed road network may have to be re-routed around unstable areas or areas where past slope failure has removed the road prism, but most portions of the road system may be useable with only minor earthwork.

When roads are planned for reconstruction, and to be a part of the permanent and seasonal road network, it is best to anticipate upgrading all drainage structures to current design standards (50-year flow) and redesigning road surface drainage to more modern standards (e.g., outsloping with rolling dips). ***Forest Practice regulations require replacement and upgrading of all undersized culverts on watercourse crossings that need reconstruction.***

3. Selecting favorable ground for new roads: In laying out a new road system in a watershed, the most favorable ground should be identified and utilized wherever possible. Favorable ground consists of ridges, saddles, natural benches and flatter natural slopes. Less excavation is needed if the road is built in comparatively low gradient areas and utilizes natural benches. Terrain to avoid includes hard rock areas, inner gorge slopes, steep slopes, watercourse and lake protection zones, highly credible soils, wet areas and swamps, areas of unstable soils and sensitive wildlife habitat

4. Road routing through difficult terrain: Avoidance is almost always the best solution to road-building in difficult terrain. Indeed, the recognition and avoidance of unstable slopes is without doubt the most effective and cost-efficient method of managing landslide-prone terrain. When possible, all serious obstacles to road construction should be avoided through complete realignment or by locally changing grade and circumventing problem spots as they are encountered. **It is far better to plan for a route containing fluctuating grades than to build a straight road which ignores the landscape through which it traverses.** Construction and maintenance costs will be minimized by sticking to the most favorable terrain.

In order of priority, the road planner and designer should consider:

1. Avoiding	unstable slopes or soils,
2. Preventing	destabilization, using special road building techniques, when potentially unstable slopes cannot be avoided,
3. Stabilizing	slopes which show signs of instability using special techniques developed by a trained engineer/geologist,
4. Protecting	downslope resources when an unstable area cannot be physically or economically avoided, prevented or stabilized.

If it is impossible to move the alignment to avoid serious obstacles, construction costs and maintenance requirements are likely to climb sharply as special construction techniques (such as endhauling) are employed to build a stable road bench and to minimize post-construction erosion.

E. Preliminary road location

The road should be plotted and located by a person with some knowledge of the area to be served by the road and of the terrain where the road is to be built. A tentative road location should first be roughly plotted on aerial photographs and topographic maps. At this stage, several alternate routes should be developed and plotted for investigation during later field reconnaissance. These alternative locations should be visually fitted to the topography (paralleling the contour lines) as much as possible to minimize cutting and filling. Aerial photos are useful for identifying natural features on the landscape that don't show up on the topographic map.

One procedure for plotting an alignment on topographic maps is shown in Figure 11. Using the known contour interval printed on the map, together with a set of measuring dividers, you can easily plot a tentative course for the road while keeping within the allowable grade limits. By combining this method with observations from aerial photographs, some of the recognizable obstacles and control points can be located, and a route with a suitable average grade can be identified and plotted on the topographic map.

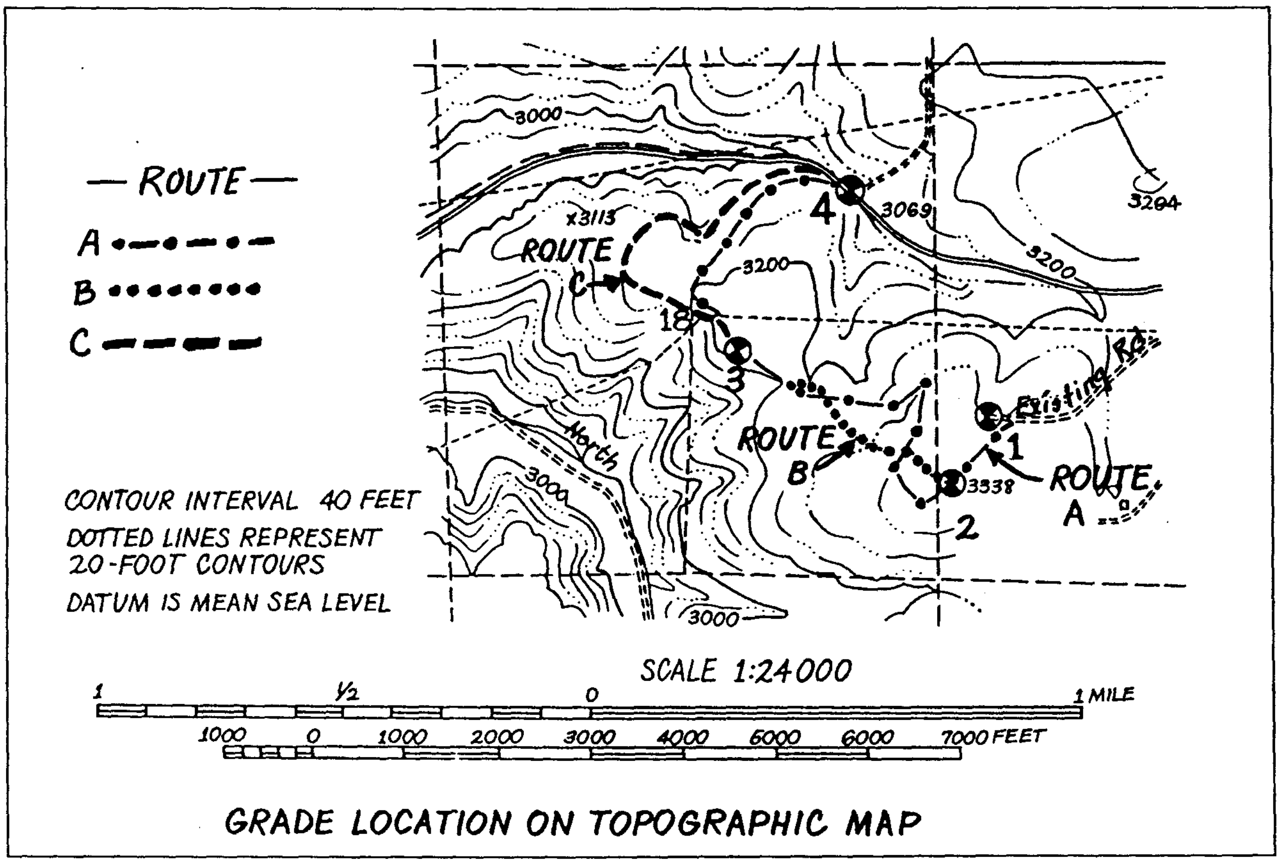


Figure 11. *On this topographic map, three preliminary road routes across a hillside have been identified. Identifying possible alternate routes on maps and photos can save time and money when the next step of field reconnaissance is performed. Several alternate routes should always be identified in the planning process since field conditions may require minor or major adjustment of the route (USDA-SCS1981).*

Table 9 shows the computations for the example in Figure 11, including three possible alignments for a road to be built from point "1" to point "4." A simple, 6-step methodology can be followed to arrive at these "paper alignments."

Table 9. Control section and grade computations for three possible road routes (see Figure 11)[1]

Route	Road reach	Elevation diff. between control points (ft)	Est. road dist. between control points (ft)	Estimated avg.road grade (%)	Caliper dist. setting	Meas'd road dist. (ft)	New est. road grade (%)	Comment
A	1 to 2	+58	800	+7	290	800	7	route is too long; try again
	2 to 3	-128	3200	-4	500	3200	4	
	3 to 4	-150	2400	-6	330	2200	7	
B	1 to 2	+58	800	+7	290	800	7	route OK; field check
	2 to 3	-128	2000	-6	330	2100	6	
	3 to 4	-150	2400	-6	330	2200	7	
C	1 to 2	+58	800	+7	290	800	7	route OK; field check
	2 to 3	-128	2000	-6	330	2100	6	
	3 to 4	-150	3000	-6	400	2600	6	

[1] *USDA-SCS (1981)*

1. Mark the beginning (1) and ending points (4) of the road.
2. Mark other known control points along the route (control points are natural features that dictate road location, such as a stream crossing, rock outcrop or saddle in a ridge).
3. Compute the elevation difference between each control point
4. Compute the estimated average grade of each road segment between control points (dividing the difference in elevation between two points by the length of road between them gives the sustained or overall grade of the road segment).
5. On a divider, set the scale distance equal to the contour interval divided by the decimal percent grade (distance = C.L/grade). Then, simply mark the primary and alternate road alignments using the dividers as set, and move from one contour line to the next

For example:

Contour interval = 40 feet

Max. desired grade = 8%, (or .08)

Computation: 40/.08 = 500 feet

In this example, you must go 500 feet before climbing 40 feet to keep the grade to 8%. The dividers should be set at a spacing equal to 500 feet on the map. Then the dividers can be used to mark where the proposed road will cross each contour line on the map (at 500 foot intervals).

6. If any road segment fails to reach the identified control points or endpoints, or if the required grade between these points would be too steep, then either individual segments or the whole road needs to be re-routed until each alternative segment and grade is satisfactory.

With several alternative alignments available, at least on paper, several other tests can be made *before* going out in the field to scout the routes. You can overlay the routes with soil maps to identify potentially unstable or erodible sites. Aerial photos can be viewed to identify possible landslides or rock outcrops that lie in the path of one or more of the routes. Ownership boundaries can be identified and, if necessary, permission can be secured to scout possible alignments that lie on adjacent property.

For most roads, half a day spent in the office can save much wasted time in the field trying to identify possible alignments for the road. Remember, topographic maps are not always accurate in the small details of the landscape, so no alignment is satisfactory until field reconnaissance is performed. Most small benches, streams and unstable areas will not show up on the standard 1:24,000 scale topographic sheet. However, general routing of the alignment, from starting point to ending point, can be performed ahead of time and then be used to guide subsequent field work.

NOTES:

CHAPTER III: FIELD RECONNAISSANCE AND LOCATION

A. Scouting the alignment

Now it's time to walk proposed routes on the ground, to scout, measure and record the actual field conditions, and to determine the feasibility, advantages and disadvantages of each alignment. If another route looks good in the field, don't hesitate to walk it, flag it, record observations and grades, and plot its position on the map. **Remember, road building is the main destabilizing activity carried out in forestry and wildland management, and avoidance is the most cost-effective means of dealing with unstable terrain.** Steer clear of sensitive obstacles such as unstable slopes, credible soils and steep stream canyons.

First, the entire length of the proposed road is walked to become familiar with the topography and ground conditions and to identify important features that were not visible on the aerial photos or topographic map. Items and conditions to identify and locate on the map in this first reconnaissance include:

1. favorable topography (especially benches and low gradient areas for landings, turnouts and spoil disposal),
2. control points (the beginning and ending points, saddles and other sites),
3. obstacles (especially unstable or erodible soils, large rock outcrops and wet areas),
4. stream channels (including their degree of incision),
5. inner gorge locations,
6. areas of steep slopes and
7. any other obvious hazards or controls.

It is important that all control points be noted at this time, with only a minimum of marking (flagging) necessary to indicate the route traveled, along with any other important features to either utilize or avoid.

B. Recognizing hazards and obstacles

Identifying many "obstacles" or hazards in the field can be fairly simple. Streams, surface wet areas (springs and seeps), rock outcrops and steep slopes are usually readily apparent. Other potential obstacles to a stable road may take training and experience to identify. These include sensitive wildlife habitat, archaeological sites, and a variety of "hazardous" hydrologic and geologic conditions (Table 10). Final identification of these potential problem areas should be left to trained specialists.

Table 10. Some natural controls which affect road location[1]

Control		Comment
Saddles		Major control for road location
Ridges		Major control and often a satisfactory road site.
Stream crossings		Major control. Seek locations with gentle side slopes and locations wide enough to accommodate the road. Good sites for bridges or culverts are needed. Evaluate for migratory fish where needed. Will need Fish and Game 1603 permit.
Benches		Often a good location for road junctions, switchbacks, landings, turnouts, etc.
Cliffs or rock outcrops		Cross above or below at a safe location. Rock which can be ripped is less costly to remove than hard rock needing blasting.
Slides		Major control. Avoid or cross at the safest point. Ask for professional geotechnical assistance.
Wetlands (bogs, swamps, wet meadows)		Major control. Avoid where possible or cross quickly at best point. May need Fish and Game clearance.
Valley floor	wide	Low gradient, desirable road location if above the flood line. If crossing, cross and get out of floodplain quickly. Little excavation required. Fish and Game permit may be required.
	narrow	Poor location because of flooding, erosion and pollution potential and high costs to cross the stream if it meanders. Keep road above floodplain. Fish and Game 1603 permit may be required.
Slopes	>40%, but <60%	Avoid sidecasting and sliver fills (thin blankets of fill placed on steep slopes) in which large bare areas arc exposed to erosion. This loose sediment may be difficult to control because of long buffers needed.
	≥60%	Construction in unstable areas should be avoided. Full bench road construction and endhauling material may be needed where slopes remain steep alongside stream channels. **Proceed only with extreme caution.** Avoid road construction on these steep slopes if possible.
	ridge crest	Good alignment and little excavation. Good drainage. Few culverts required. Adverse grade encountered on uneven ridges. Spur roads will have an adverse grade.
Aspect		Maintenance requirements in moist climates can be minimized by placing roads on south-facing slopes to promote drying and snow melt. In dry climates, (he north-facing dopes have more vegetation and may have less erosion. Extremely wet or dry climate negates this effect.
Rock slope (dip)		Place roads on (he hillside where rocks dip (slant) into the hillside, not parallel to or out of the hillslope. Consult a geologist for other problems and advice.
Soils		Where possible, avoid road building on naturally erodible soils. Check soils maps for potential problems and ask extension agents or the SCS for advice. Frozen soils require special care; ask for assistance.

[1] *modified from USDA-SCS (1981)*

For example, a geologist may be needed to locate unstable subsurface geology, soft or weak bedrock materials, contact zones and faults, rock layering that is susceptible to failure when undercut by road construction, existing and potential landslide areas, potentially unstable stream banks and stream crossing sites, and the suitability of local spoil material for use in road fills and stream crossings. Many of these conditions may not be apparent to the untrained observer. It is important to identify all the unstable areas along the proposed alignment and treat them as control points. Avoid unstable areas and poor stream crossing sites by linking up all the stable slopes and suitable crossings locations.

When a final alignment has been identified, a trained wildlife biologist may be required to investigate the alignment and the surrounding terrain for endangered species or species of special concern. An archaeologist may occasionally be needed to identify cultural sites that have to be avoided or mitigated before construction can begin.

If you are unsure whether or not you need specialized advice, ask the Department of Fish and Game (for wildlife issues), the Soil Conservation Service (for reading activities on private non-timber lands), and/or the Department of Forestry and Fire Protection (for reading activities on private timberlands). They won't do the technical consulting work for you, but they can give you pointers, provide advice about the need for additional help and describe where to find it.

Specialists identify problems, suggest alternate alignments to avoid many of these problem areas, and design mitigations for problems areas that cannot be avoided. The expense of these professional consultations is, in most cases, well justified and quickly repaid by lower construction and maintenance costs over the first few years of the road's existence. Benefits are also gained from minimizing impacts to watercourses along the alignment So called "low-cost" roads can be very expensive if they are poorly planned and constructed, while roads which initially cost slightly more to build often end up costing far less in the long run when lower maintenance and rebuilding costs are accounted for.

C. Marking the proposed alignment

First, a preliminary traverse of the approximate route(s) is conducted. For this, and later detailed field layout, the following tools and materials should be carried:

1. a hand-held clinometer or abney level (to measure road grades and hillslope gradients),
2. a measuring tape, range finder or hip-chain (to measure distances),
3. an altimeter (to measure elevations),
4. colored flagging (for marking the alignment, hazards and obstacles),
5. a hand compass (to check bearings), and
6. a map and/or aerial photos (showing the alternative alignments plotted earlier).

Next, a preliminary road location survey is conducted, using one or two people. Based on the first traverse, and the identification of obstacles and hazards, a tentative route is identified on the ground. Beginning at one end, the center line of the route is roughly marked with flagging along a pre-selected grade line (the average grade of this route was determined in the 6-step map procedure described earlier). Grade between each flag is measured using a clinometer or an abney level. Ragging, by convention, may be hung on the approximate centerline, or they may be hung to mark the top edge of the cutbank (so they aren't destroyed during construction). If the predetermined fixed grade does not exactly meet the desired ending point, you can work back from that endpoint and connect the two surveys at a convenient location.

Once this preliminary alignment has been established, you should "stand back" and examine the route to determine where adjustments in grade and alignment could be made to take advantage of benches and gentle ground, while avoiding unstable sites, wet areas, incised stream channels and rock outcrops. Some steep pitches may be necessary to reach the best ground for the road. For example, efforts should be made to identify and utilize the most suitable, stable and least incised stream crossing sites, and potential WLPZ areas should be avoided. Broad ridge crests and benches should be identified and flagged as possible locations for landings, road turnouts and spoil disposal sites (Figure 12). Nearby rock outcrops should be identified and evaluated for potential rock aggregate for road surfacing materials. After evaluating all these factors, several additional grade surveys may be needed to identify and mark the final and best location for the road.

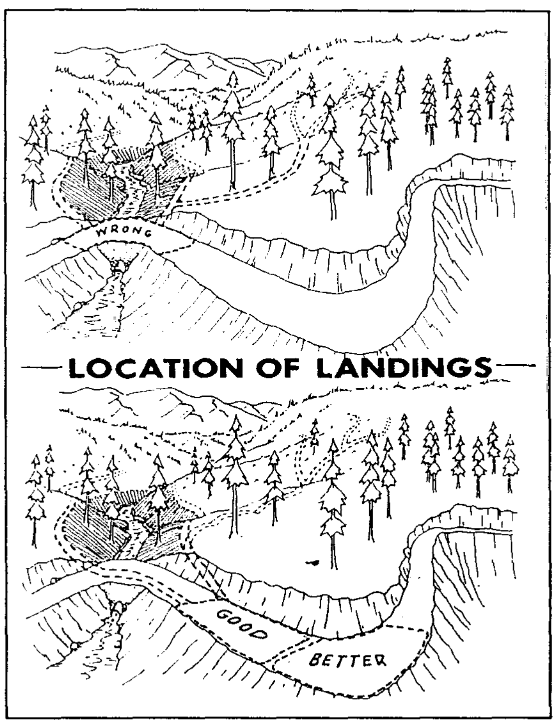


Figure 12. Log landings on forest road systems should be kept to the absolute minimum size necessary to accommodate yarding, loading and hauling equipment and the minimum number needed to remove timber resources. Landings constructed on gentle ground and broad ridge crests far removed from stream channels are least likely to cause water quality problems, whereas landings built on steep slopes and near watercourses can result in severe impacts (USFS, 1963).

The marking of curves and switchbacks requires a little more thought and care during road layout. Each turn should be of sufficient radius for trucks and the anticipated equipment to negotiate easily and safely. The radius should be no less than 35 feet for standard pickups and field vehicles, and 55 feet for tractor trailers (such as log trucks). A minimum horizontal curve radius of 200 feet is suggested for roads supporting 20 mph traffic (Table 6).

Where curves are short and gentle, they can be located by eye to follow the topography and the flagged grade location. Sharper curves and switchbacks require some surveying. The center stake method is one of the simplest methods for marking these curves during the road survey. First, decide on the radius of the curve (see Table 11). Then, using a string or a tape that is the length of the desired radius (or using a range finder), simply identify and stake the center of the curve and stake the centerline in an arc extending out from the center stake (Figure 13).

Table 11. How to convert horizontal distances to true "slope distances" measured on hillslopes needed for marking road curves and switchbacks[1]

When the land slope is this steep in the direction you're looking (use a clinometer)...	...true slope distance is determined by multiplying horizontal distance by the following correction factor...
10%	1
15	1.01
20	1.02
25	1.03
30	1.04
35	1.06
40	1.08
45	1.10
50	1.12
55	1.14
60	1.17
65	1.19
70	1.22

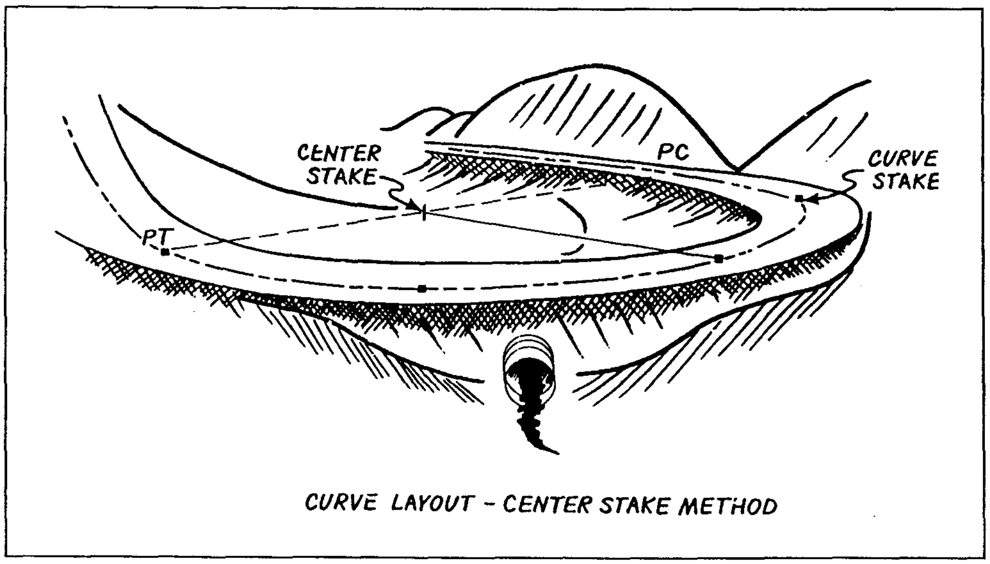


Figure 13. *Staking and identifying simple curve layout using the center stake method (USDA -SCS, 1983).*

The Center Stake Method assumes the ground is flat as you're marking the arc. This isn't usually true, so some adjustment of the lengths marked in the field is needed to compensate for the slope of the hillside (see Table 11). To use the center stake method, true horizontal distances need to be marked on the ground. To get the slope distance, multiply the horizontal distance (desired curve radius) by the correct multiplier shown in Table 11. For example, to switch back across the slope above with a 110 foot horizontal radius on a hillside with a 65% slope, the curve should be marked 131 feet upslope (110' x 1.19 = 131') and 131 feet downslope from the center stake. Straight ahead, on contour, the stake is marked at 110 feet.

Ideally, the road within a switchback should have little or no grade so that trucks and equipment can pass safely and so they won't tear up the road surface while turning the comer and continuing up the road. This may require increasing the average grade of the road coming into and leaving the switchback. Depending on the curve radius, the grade of the road should at least be reduced through the curve to provide for safe handling of vehicles and equipment (Table 12). Where longer curves are needed, the Stick Method of curve layout may be more convenient (see Appendix D).

Table 12. Suggested reductions in road grade through curves of different radius[1]

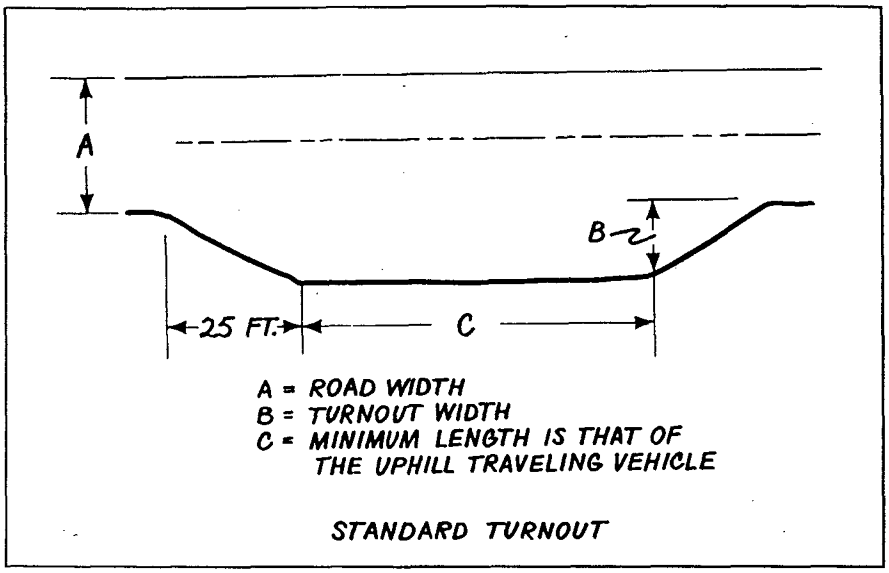
Curve radius (ft)	Reduction in % road grade
150 to 460	1%
90 to 150	2%
65 to 90	3%
50 to 65	4%

[1] *USDA-SCS (1981). It is suggested that road grades through switchback curves be flat (0%), or very low.*

Landings and turnouts should be identified and staked at the same time curves are staked. Typically, turnouts should be intervisible and located where a minimum of excavation will be required to increased the road width (Figure 14). Landings should be the minimum length and width necessary to accommodate the yarding and loading equipment. Some mobile yarders can work directly off a single lane road or at turnout locations, and landings need not be built On roads to be reconstructed, existing, stable landings should be re-used and landing enlargement or expansion should be avoided wherever possible.

For situations that require a more highly engineered road than can be marked using a centerline location survey (e.g., where slopes are very steep, or where sidecasting is not permitted), it may be necessary to set grade and slope stakes. In this procedure, stakes are placed at 50- to 100-foot intervals along the alignment, depending on topography. For sidecast constructed roads, grade stakes are first placed at points in the cross section of the road where the cut and fill sections meet and are reduced to zero. A follow-up survey is then run to set cut and/or fill stakes marking points on the ground that will be at the top of the cutbank or the toe of the fill, respectively. Grade surveying may then be used to obtain accurate estimates of cut and fill volumes.

re ***14.*** *Standard turnouts allow for les to pass each other by safely ıg off and back onto a single lane Turnouts and landings should be ed to take advantage of benches and 1 ridges where the additional road can be developed with a minimum of 1 excavation. Turnouts should be visible (USDA-SCS, 1983).*



Notes:

CHAPTER IV: DESIGN

A. Introduction to road design

Road design is often a combined result of economic and environmental factors that influence construction, operating and maintenance costs. Unfortunately, because construction costs are felt immediately, they are often the sole consideration employed in choosing a road's final design. However, excessive hauling expenses and difficulty of travel on a road, as well as high road maintenance costs, may have a far greater effect on the long-term economics of forest or ranch operations than the savings in initial construction of a low standard or inadequately designed road.

Over-design can also be a costly mistake. For example, construction costs for a 12-foot wide road on a steep side slope may be as much as 30% higher than for a 10-foot wide road in the same location, because of the large volume of earth that must be moved from the inside of the road bench to obtain an additional two feet of road width. Long-term maintenance costs are also likely to be higher for the wider road. For this reason, it is important to determine the main types of vehicles and the expected volume and speed of traffic so that the required road standards can be established well before actual construction begins.

Both road length and road width should be designed to minimum standards for the anticipated uses of the road. Narrow roads dramatically reduce excavation and sidecast volumes, thereby reducing cutbank height and decreasing the likelihood of slope failures (Table 13).

Road design begins with planning for the road's location. Selection of the final route will constrain many future design decisions. Two important design questions that need to be answered early in the planning process are 1) road prism design and 2) road surface design. Routing the alignment through or around various obstacles and hazards calls for the use of certain road prism designs. In addition to these, there are special situations that often arise and require special road design considerations.

Hillslope gradient (%)	Excavated volume to construct a full bench road (assumes ½ : 1 cutbanks) (yds^3 excavated per ft of road)			
	Road width 12 feet	Road width 14 feet	Road width 16 feet	Road width 18 feet
30	0.94	1.28	1.62	2.17
35	1.13	1.54	2.01	2.55
40	1.33	1.82	2.37	3.00
45	1.55	2.10	2.75	3.48
50	1.78	2.42	3.16	4.00
55	2.02	2.81	3.60	4.55
60	2.28	3.11	4.06	5.14
65	2.57	3.50	4.57	5.78
70	2.87	3.91	5.11	6.46
75	3.20	4.36	5.69	7.20

Table 13. Excavated soil volume for full bench roads with various road widths and hillslope gradients (yds^3/ft)

B. Road prism design

Road prisms may be designed to be **full bench, partial bench** (part cut and part fill, including designs employing sidecasdng) or **full fill** (Figure 15). Roads which are constructed without endhauling are **partial bench** roads where spoil generated during initial grading is used to widen the roadbed and fill depressions and stream channels crossed by the road. This has been the most commonly used construction practice for rural forest and ranch roads. The fill is either placed and compacted, or (more commonly) sidecast loosely into the desired location. However, there are many circumstances where sidecastmg is no longer acceptable and alternative designs and methods are needed and required to reduce environmental impacts and to provide a stable road bed.

Roads may need to be **full bench** on steep slopes (those over about 60%), in watercourse protection zones, or where water quality could be impacted by road work (Figure 16). Full bench construction requires that all the spoil generated by cutting into the hillside must be either used in filling local stream crossings and low spots in the new road, or endhauled to a stable storage site where spoil has no risk of entering a watercourse.

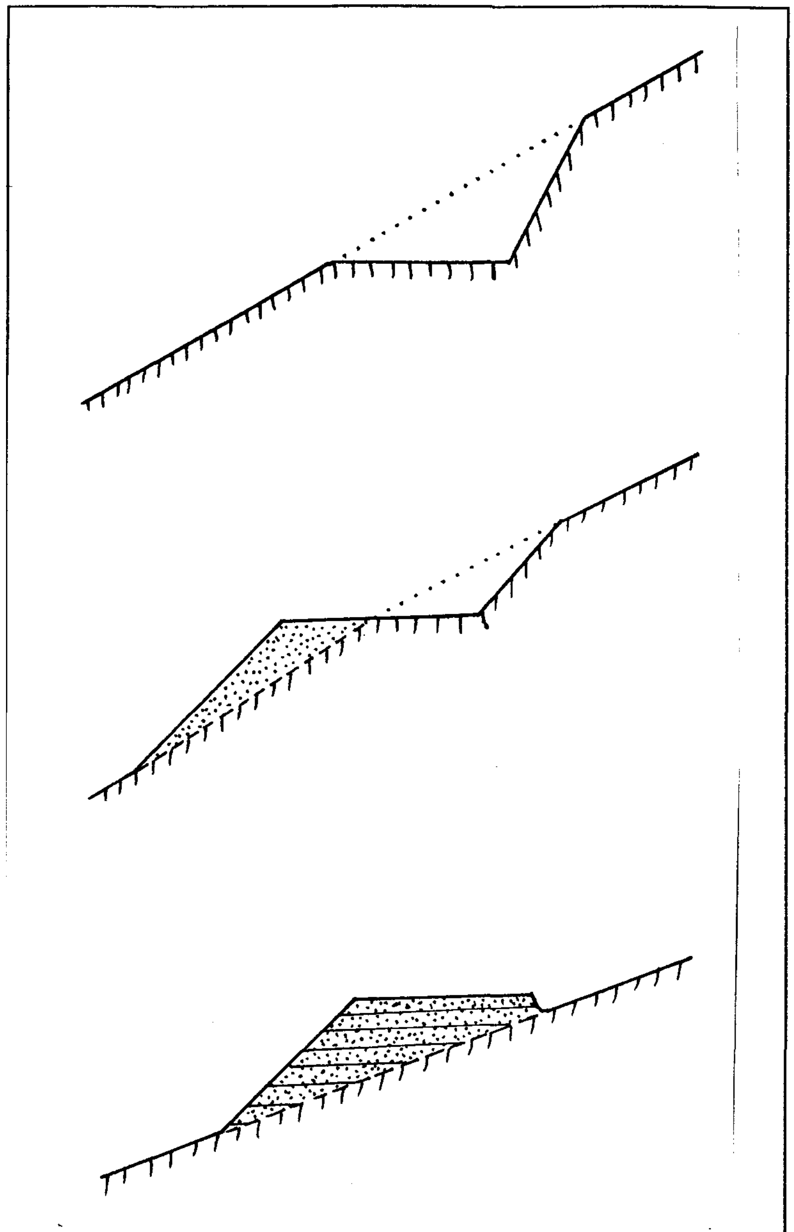


Figure 15. *Idealized diagrams depicting a full bench road (all material endhauled - no sidecasting)(top); a partial bench road (with both cut and sidecast)(center); and-a full fill road (no cut - all fill placed and compacted in shallow layers)* ***(bottom).***

Road segments constructed with **full fill** techniques are somewhat uncommon at the present time, but growing in importance. Roads using this technique are usually confined to short reaches where slopes are potentially unstable and cuts into the slope could trigger soil movement Full fill sections of road are often supported by structurally engineered fills with near-vertical fill faces. Full fill road construction is also used where roads cross incised stream channels and the road is built entirely on fill material.

Cut-and-fill design: For most forest- and ranch-land owners, use of cut-and-fill road construction has been preferred because it minimizes the amount and cost of earth moving. In other words, less soil moved generally means less expense (Figure 17).

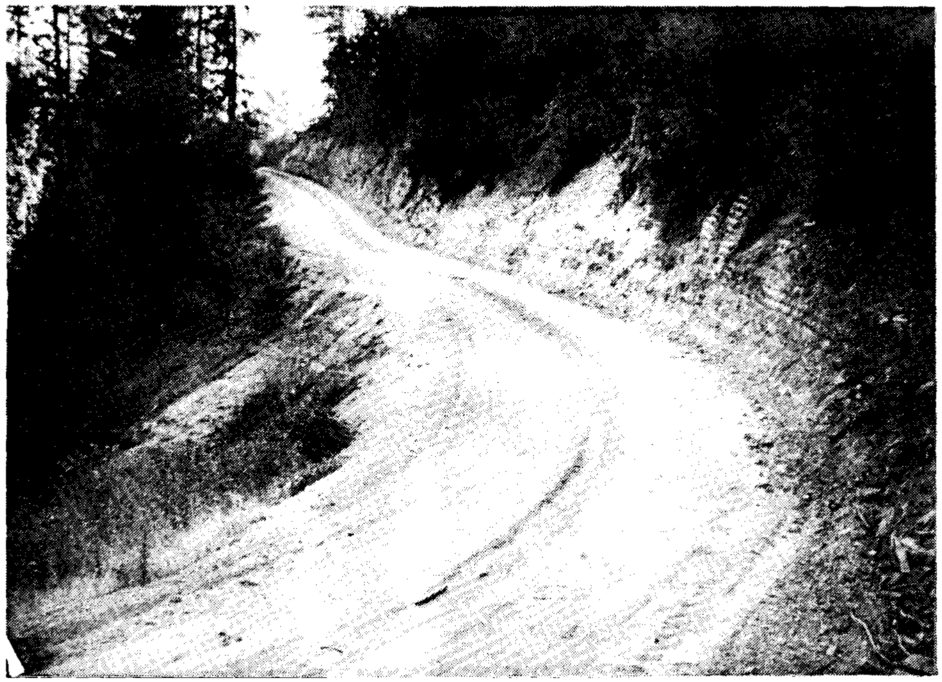


Figure 16. Full bench road. The height of the cutbank, the slope of the natural hillslope and the small amount of sidecast indicates that this road is full bench and cut entirely into native hillslope materials. Note that the road is outsloped with rolling dips and no inboard ditch.

***Figure** 17. In contrast to the road in Figure 16, this partial bench road was built by extensive sidecasting. At least half the roadbed is built on fill materials.*

However, the indiscriminate use of sidecast road construction (the simplest method of cut-and-fill construction) has probably caused more problems for landowners than any other type of road building. Sidecasting construction techniques should not be used on slopes over 55 percent because this results in fillslopes of about 67 percent, the average angle of repose (stability) for most loose soil materials (Figure 18). For this reason, sidecast construction should be limited to gently sloping areas where streams are far from the road prism. Cut-and-fill construction techniques can be used on slightly steeper slopes *if* proper compaction techniques are used.

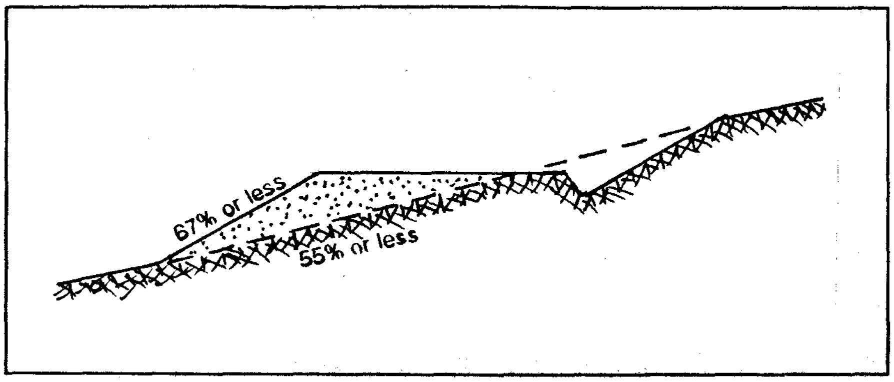


Figure IS. *For most earth materials, sidecasting on natural slopes over about 55%* ***in*** *steepness will result in steep, loose, unstable sidecast slopes that are easily eroded or prone to sliding. The face of a sidecast slope should not exceed about 67%, the maximum angle of stability for most uncompacted, sidecast soil material.*

In general, cuts should equal the needed fill volume, plus about 20 percent to allow for settling of loose fill. That is, the loosened, excavated soil will take up about 20% more space than when it was "in-place." During the process of cutting and filling, it is critical to avoid letting sidecast or waste material enter streams or watercourses, or placing it on unstable or steep slopes where it might erode.

The angle or steepness of both cut and fillslopes is very important in building stable roads. There is a tradeoff in determining the optimum cutslope angle (Table 14). Cutbank slopes should be designed to achieve maximum stability as well as a minimum exposure of bare soils. On balance, cutbanks should be as steep as the soils and bedrock will permit without becoming unstable.

Table 14. Advantages and disadvantages of steep cutslopes[1]

Advantages of steep cutslopes	**Disadvantages of steep cutbank**
1. Less right-of-way	1. Difficult to revegetate
2. Less excavated material	2. Prone to ravelling
3. Less sidecast	3. Prone to tension cracks and failure
4. Shorter slope exposed to surface erosion	4. Slightly greater risk of a rotational slope failure.

[1] B.C.M.F. (1991)

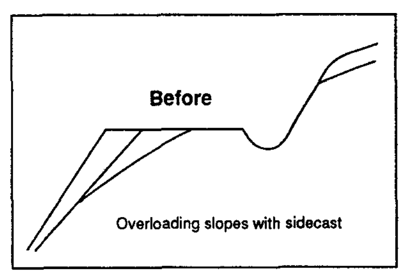
Cut and fillslopes are usually expressed as ratios, such as ½: 1 or 1:1 (Table 1). Road banks can be cut as steep as the stability of the material will permit, ranging from ¼ : 1 for very stable rock materials to 3:1 for erodible or unstable soils (Table 15). A general guide for the maximum steepness of road cuts in various rock and soil materials is shown below. Note that wet slopes, unstable or erodible soils, and highly fractured or bedded rocks may require gentler slope cuts.

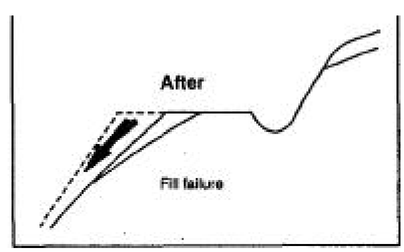
Cut height and cut angle also affect the stability of the final cutslope. Cuts which are stable at ½: 1 at a 6-foot height may not be stable when the cut height is twice as high at 12 feet. Higher cuts lead to increased gravitational force and reduced stability at the face of the slope. Tall (deep) cuts are also more likely to intercept emerging soil water that can weaken the cutslope and cause failures that block the road or result in persistent ditch and roadbed maintenance problems.

Table 15. Generalized maximum cut and fill steepness for different earth materials	
Slope ratio	**Earth material**
¼ to l	Rock cuts
½ to l	Hardpan & soft rock cuts
¾ to 1	Clay
1 to l	Clay, sandy or gravel alluvium
1 ½ to 1	Fillslopes, lake deposits
2 to l	Unstabilized, uncompacted soil
3 to l	Unstabilized soil
Near vertical to sloping: use only where such cuts are working locally	Some sandy or granitic soils; some hard bedrock exposures

Fillslopes can be built to a variety of angles depending on the properties of the material used, the amount of properly applied compaction, soil moisture and the type and density of vegetation that is established on the surface. In general, thick accumulations of loose, dry, side-casted soil that is not compacted will not usually hold a slope over about 65 percent, whereas many fill materials that are placed and properly compacted in thin, 1-foot layers may be stable at slopes well over *1* ½ to 1 (67%). While a thin veneer of sidecast may hold on a slope steeper than 65%, a thick wedge of loose sidecast may not be stable even at a 50% slope (Figure 19). Stable road fills can be built on moderate and steep slopes by using layered compaction methods. Here, a bench is excavated at the base of the proposed fill, and layers of compacted soil are built up on this stable bench. The stability of the fill can be further increased by starting with an insloped bench that helps "key" the fill to the slope.

Figure 19. *Overloading steep slopes with uncompacted sidecast material can result in landsliding that damages streams hundreds of feet downslope(B.C,M-F.,1991).*





In critical areas, engineered fills that utilize reinforcing fabrics or other internal supports can be constructed with nearly vertical faces. These are especially useful in short road sections where other fills would be unstable or erode and sediment could enter a watercourse. In such cases, it may be necessary or prudent to employ a geotechnical engineer to design a stable cut and fill road. Depending on the stability of the cutslope rock and soil materials, it may be simpler and cheaper to construct a full bench road where all the excavated material is simply endhauled off-site and deposited in a stable storage site.

C. Road surface design

Road surface design is really ***road surface drainage design,*** and should be chosen based on both maintaining safety for the intended uses and minimizing erosion and sediment pollution in streams. Road surfaces can be designed as **insloped, crowned, or outsloped.** It is critical to properly design road surfaces to minimize erosion from the road bed, ditch, cutbank and fillslope surfaces.

1. Insloped and crowned roads

Insloped and crowned roads drain surface runoff to the inside of the roadbed, often into a ditch, where it is combined with flow from the cutslope and upslope hillside areas and discharged through culverts. Insloped roads are often used where an inside ditch is needed to keep soil water emerging from the cutslope off the road surface (Figure 20). To keep ditch flow to a minimum, it is also possible to build an outsloped road with an inside ditch to carry away water from the cutbank and from upslope areas. Crowned roads drain water both ways from the center of the road, but an inside ditch is still required.

Well constructed and maintained ditches are a real key to long-term stability of an insloped road. Backhoe and excavator constructed ditches are often superior to bladed ditches built by a bulldozer or grader because they can be cut out of the subgrade rather than gouged into the cutbank. The ditch cross section should be designed to accommodate expected storm flows, with the base of the ditch at least 12 inches below the roadway in order to prevent water from entering the road surface material and removing the fines. A relatively deep ditch also allows for faster drainage of the subgrade and helps maintain high soil strength.

Ditch gradients on insloped roads should be steep enough (generally over 1.5%, and ranging from 2% to 6%) to prevent sediment deposition and allow rapid drainage, but not so steep as to result in ditch erosion. When inside ditches are used, frequent ditch relief culverts should be installed to minimize the concentration of runoff in the ditch and to disperse runoff to downslope areas. It is recommended that a minimum 18 inch diameter pipe be used for ditch relief culverts. A general rule-of-thumb is to install the culvert at a grade 2% steeper than the ditch grade, and to skew the culvert at a 30° angle to the ditch line to minimize inlet erosion and to transport sediment through the culvert. Culvert outfalls should be protected with slash and/or rock armor to prevent erosion of the fill. Where sedimentation at the inlet occurs because of over-steepened cutbanks, drop inlets can be installed to prevent culvert plugging. On steep roads over about 10%, even small volumes of ditch flow may have high enough flow velocities to cause erosion of the ditch. In this case, it may also be necessary to armor the ditch to prevent erosion.

The capacity of ditches should also be planned and designed to accommodate flood flows from large storms. If stream crossing culverts along the road are designed to accommodate a 50-year flood flow, the ditches should probably be designed to the same standard. Flat-bottomed ditches (which are easily cut by backhoes and excavators) are less subject to scour than V-bottom ditches that are commonly created by bladed tractors and graders. A 1-2 foot bottom-width is recommended.

2. Outsloped roads

Outsloped roads are typically less expensive to construct and less difficult and expensive to maintain than insloped roads. For example, building a 12-foot wide insloped road with a 3-foot wide inside ditch requires moving almost 60 percent more material during construction than if the road were outsloped with no ditch (Table 13). Clearly, if conditions permit, roads should be constructed with an outsloped surface, no ditch and no berms along the outside edge of the road.

Outsloped roads also disperse and drain runoff along the entire outside edge of the road. Rolling dips and a smooth road surface are key to maintaining a well drained, outsloped road. The frequency of rolling dips and grade breaks, and the amount of "outsloping" needed to drain the road surface, depends on the grade of the road, as well as the road surfacing. Table 16 shows design criteria for the degree of outsloping needed to drain road surfaces on differing grades.

Table 16. Outsloping "pitch" for roads up to 8% grade[1]

Road grade	Outslope "pitch" for unsurfaced roads	Outslope "pitch" for surfaced roads
4%, or less	3/8" per foot	1/2" per foot
5%	1/2" per foot	5/8" per foot
6%	5/8" per foot	3/4" per foot
7%	3/4" per foot	7/8" per foot
8%, or more	1" per foot	1 ¼" per foot

[1] *CDF(1984)*

Where fillslopes are stable, roads should be designed and constructed with minimum width and with a mild outslope (3-4%) (Figure 20). However, on most roads, especially those with grades in excess of eight percent (8%), outsloping is not always enough to get surface flow off the road quickly. Here, in addition to outsloping, waterbars (for seasonal or temporary roads) or rolling dips (for permanent and seasonal roads) are necessary to divert surface runoff.

Waterbars and rolling dips should be spaced along the road close enough together that the road surface is not gullied. It is important to use rolling dips, rather than waterbars, on roads with even infrequent use because traffic will quickly break down and/or breach the waterbars (Figure 21). Waterbars should be reserved for roads that are to have little or no winter use.

Appropriate spacing of surface drainage structures depends on soil credibility and runoff rates. Look at local roads to determine the maximum spacing that will work in your specific area. Suggested design criteria for drainage spacing (waterbars and rolling dips) is listed in Table 3 and, alternately. Table 17. Design dimensions for rolling dips are shown in Table 18.

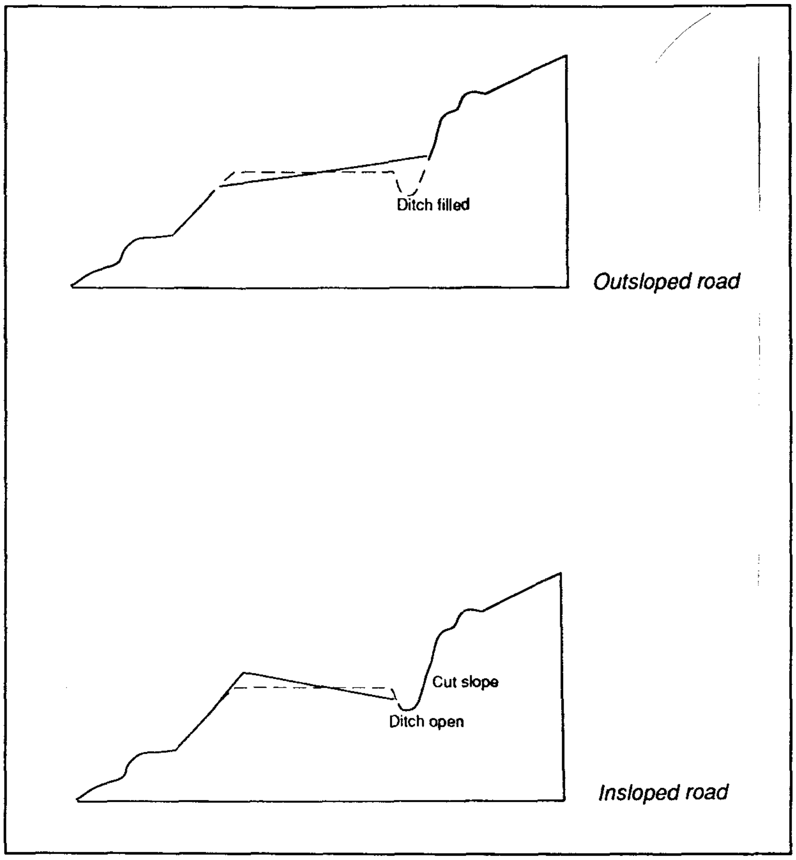


Figure 20. Outsloped road with no ditch (top), and insloped road with the ditch open (bottom). Outsloped roads are generally preferred because they disperse and drain surface runoff across the outer edge of the road prism. Insloped roads collect and concentrate road runoff into an. "inboard" ditch that is drained across the road in ditch-relief culverts. Outsloped roads are superior except where seeps and springs necessitate short segments of inboard ditch to collect and remove runoff.

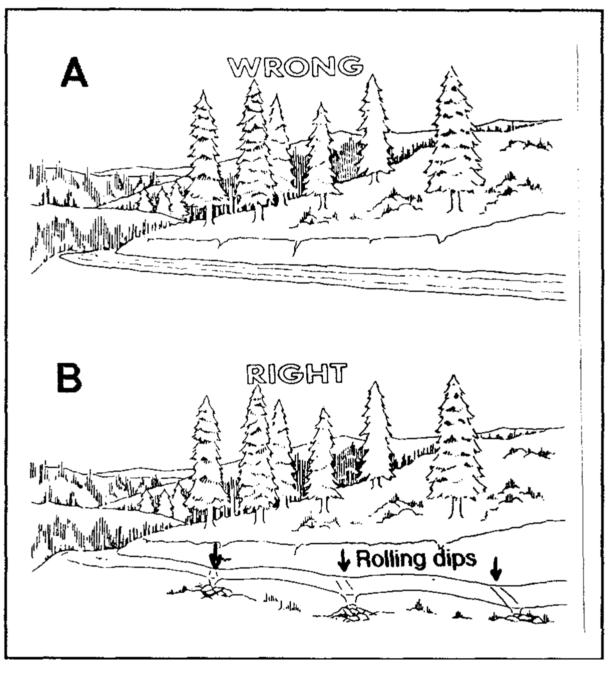


Figure 21. *Installing rolling dips, or "rolling the grade" of an outsloped road helps guarantee that surface runoff will not concentrate on the road surface and erode the roadbed.*

Table 17. Maximum suggested road surface drainage spacing based on road gradient and soil composition[1]			
Soil composition	Road gradient (%)		
	2% - 4%	5% - 8%	9% -12%
Granitic or sandy	400	300	200
Clay or loam	500	400	250
Shale or gravel	600	500	300

[1] MSS1,. (1991). Distances used. only to show importance of soil type in influencing drain spacing. Forestry operations are required to employ distances outlined in the Forest Practice Rules (Table 3) as a minimum.

Table 18. Table of rolling dip dimensions[1]				
Road grade (%)	Upslope approach[2] (distance from up-road start of rolling dip to trough)(ft)	Reverse grade[2] (distance from trough to crest) (ft)	Depth below average road grade at discharge end of trough[2] (ft)	Depth below average road grade at upslope end of trough[2] (ft)
<6	55	15-20	0.9	0.3
8	65	15-20	1.0	0.2
10	75	15-20	1.1	0.1
12	85	20-25	1.2	0.1
>12	100	20-25	1.3	0.1

[1] USDA-SCS(198l)
[2] See also Figure 28

D. Subdrainage requirements and design techniques

Subdrainage is used to carry subsurface or emergent subsurface water from the roadway. Seepage can occur along the cutbank, beneath the roadbed and/or beneath the road fill along the outside edge of the road. This can cause several problems if subsurface water is not drained from the road prism and construction area, including 1) excessively wet fills and subgrade materials, leading to road surface rutting or the need for large quantities of rock as base-course, 2) cutbank slumping, 3) mass wasting of the fill due to unrelieved pore water pressures, and 4) continual mud pumping at the road surface, leading to failure of the surfacing and the need for regular re-surfacing.

Use of special subdrainage measures is not typically required on forest and ranch roads. However, when needed, some relatively simple techniques can be used to get rid of water (Figure 22). Ditches and French drains excavated along the inside edge of the road, at the base of the cutbank, are common methods of draining emergent, upslope ground wa^er. Horizontal drain pipes can be installed to drain water from the cutbank, but this stabilization technique is expensive and not always effective.

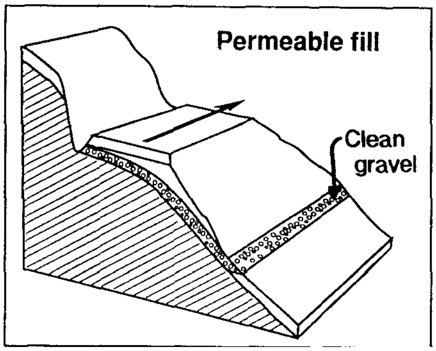
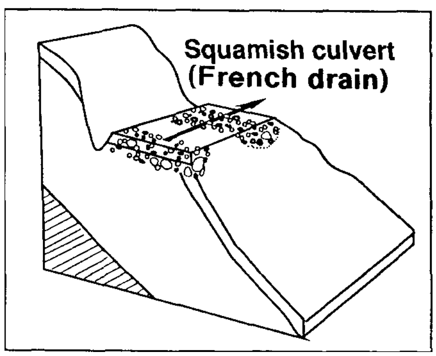
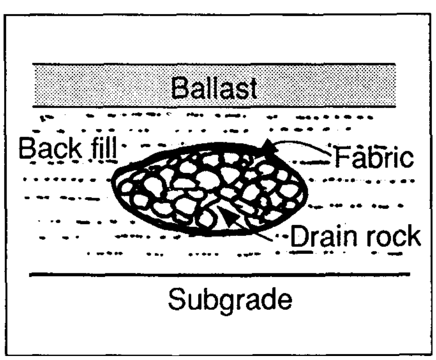


Figure 22. Roads which are built across small springs or seeps can be kept dry and stable by the use of subsurface drainage techniques. Drainage blankets (a) and "french"drains (b), using graded rock and synthetic fabrics (geotextiles), are two common methods for draining subsurface soil and rock materials. Figure lie details a close-up of the modem french drain design using a geotextile lining (B.C.M.F., 1991).





French drain

If the roadbed crosses an intermittent or perennial spring, soils beneath the road surface may need extra drainage. For water which will emerge beneath the road, gravel drainage blankets can be used to drain the water laterally to the toe of the fillslope. Filter fabrics (geotextiles) are used to maintain separation between the native hillslope materials and the I gravel. Where fills are thin, and where surfacing is placed directly on native soils, geotextiles can also be used at the base of the subgrade to maintain soil separation and prevent soil pumping into the surfacing materials.

E. Landing design and layout

Log landings built along forest roads vary tremendously in size and frequency from one landowner to the next, but their design requirements differ lime from other sections of a road system (Figure 23). Newer, mobile cable yarding machines can operate on narrow sections of road, with lime more than a turnout required for their swing. Other yarders, including towers, may require an entirely separate "yarder pad" be constructed on a spur road above the main haul road where logs are landed and then loaded onto trucks. However, such large yarding machines are becoming less commonplace.

Tractor yarding requires moderate size landings that, over the years, often grow larger than needed as spoil and debris is carried down the converging skid trail network and then sidecast over the outside edge of the landing.

The frequency of landings that need to be constructed is controlled, or influenced, by the type of yarding equipment, the slope of the land and the density of harvestable trees along the route. For example, on very steep slopes, stable landings might only be constructed on broad ridge crests. **In general, landing construction should be limited to the fewest number and smallest size that are absolutely needed for yarding operations.**

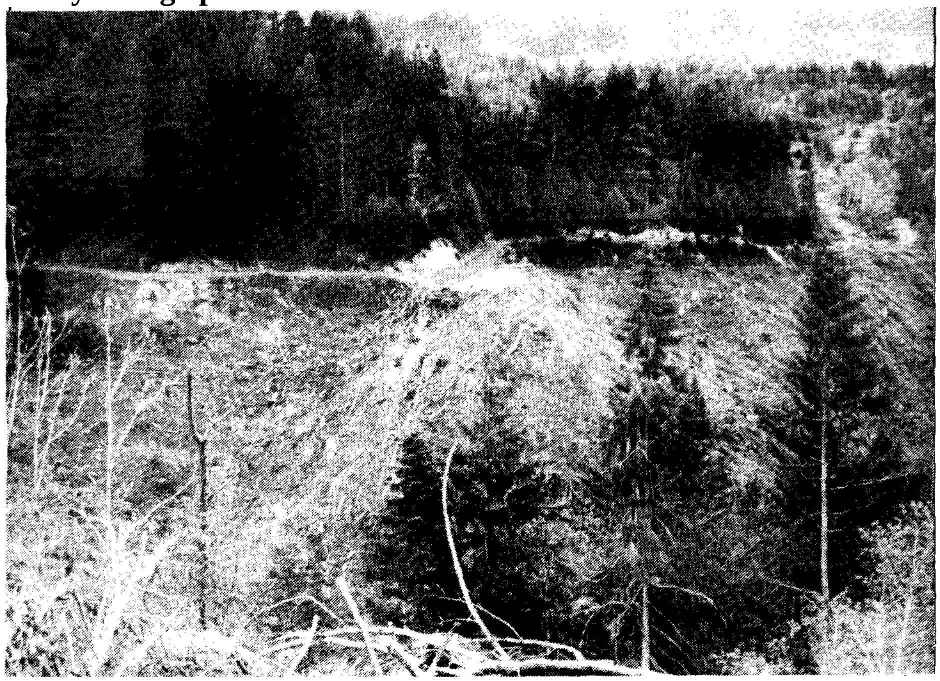


Figure 23*. Landings should be built on the nose of ridges and above the break-in-slope defining the steep inner gorge slopes above a stream channel.*

Landing fills that are placed on steep slopes or near watercourses should be "keyed" or benched into the hillslope and compacted in shallow (1 foot) lifts from the bottom up. **Sidecasting should be avoided. In addition, older landings which are being rebuilt or reused should not be enlarged by sidecasting of spoil or organic debris.** Where roads are located far from the stream, maximum hillslope gradients for building small landings using sidecasting methods should be the same as for road construction: about 55 percent. It is recommended that keyways or benches be constructed for catching sidecast and fill where landings are built on slopes steeper than about 40%.

The following terrain conditions should be avoided as sites for landings: 1) unstable slopes and soils, 2) open slopes steeper than 30 degrees (55%) with no natural benches, 3) steep headwater swales and inner gorge slopes, 4) narrow ridges between headwater swales, 5) any steep slopes (>50%) which led without flattening to a watercourse and 6) areas underlain by steeply dipping sedimentary rock or highly fractured rock.

Constructing full benches for landings on steep slopes produces tremendous volumes of spoil material. Although full benching might be necessary so that fills can withstand equipment vibrations and weight loads, spoil that is disposed of as sidecast can destabilize the hillside below. Gully headwalls and swales are already naturally unstable sites and have little room for landing debris. Sidecasting into these steep headwater swales can trigger debris flows and torrents (Figure 24). Although steep, narrow ridges adjacent these steep headwater channels provide good deflection for yarding, the sides of these ridges are often unstable and unsuitable for sidecasting.

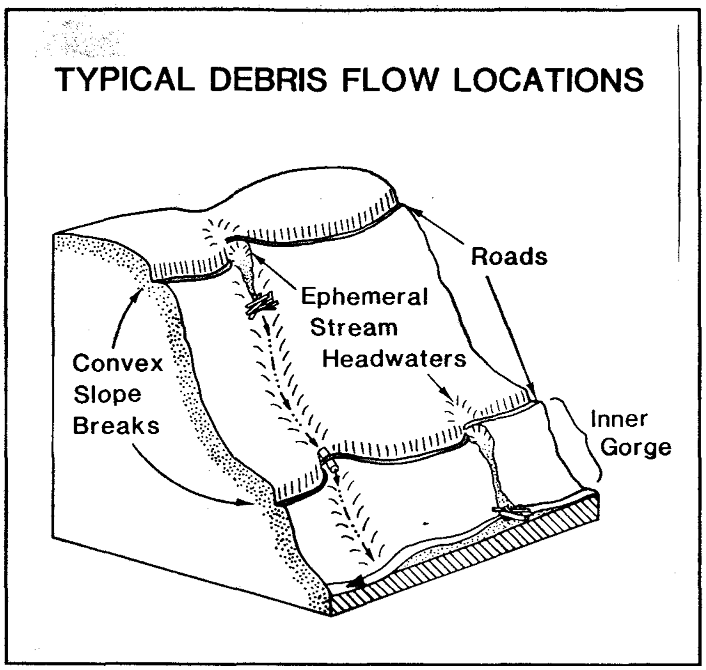


Figure 24. Recent research has shown that many destructive debris flows and debris slides caused by the construction of wildland roads occur at specific sites on the hillside. The most sensitive sites, and therefore those to avoid during road construction, are steep inner gorge slopes, steep headwater stream areas, and steep slopes immediately below a convex bread-in-slope.

F. Special design considerations

In both the forest and ranch-land setting, special design considerations may be required where roads cross unstable slopes, wet areas, watercourses and other potential hazards or obstacles. Some of these might involve using new, state-of-the-art subdrainage materials and methods. Other special designs may simply involve the application of time tested methods of equipment exclusion, excavation, endhauling, bridge installation, road surfacing or additional requirements to provide increased protection to water quality. Guides for special road design are often available from private geotechnical firms specializing in road construction, or from suppliers of materials and supplies used in erosion control and road engineering.

Converging roads on steep slopes is one special case of road construction that commonly produces erosion and sediment problems. In this situation, a lower road may undercut and remove support for the upslope road. In addition, sidecast from the upper road can extend downslope to the lower road, with continuing sidecast from the lower road then extending the blanket of bare soil downslope even farther. These bare soil areas are notably difficult to stabilize and revegetate.

The best planning and design solution for converging roads is to locate road junctions on gentler slopes, or to plan for them to occur on broad ridges separating steep gradient slopes. If steep slopes cannot be avoided, it is recommended that the upper road be constructed as a full bench road with all spoil endhauled to a stable location, and the lower road be built with an engineered fill to limit uncontrolled sidecasting. The road junction should be located sufficiently far upslope from watercourses such that water quality will not be affected. Full bench construction with endhauling, or other creative engineering solutions that minimize sidecast, may be designed for these "unavoidable" settings where the potential for sedimentation or slope failure is relatively high.

G. Equipment needs for construction and reconstruction

Construction is the application or implementation of road design on the ground. How well the design is followed during construction depends both on the skill and understanding of the equipment operators and the type and size of heavy equipment used for each task. For example, constructing a full bench road with endhauled spoil material requires suitable excavating equipment. A tractor will not work, especially on moderate or steep slopes. Similarly, without a skilled equipment operator, there is a much higher chance of making expensive mistakes or causing environmental damage.

In steep or mountainous areas, it is often a serious mistake to design the road around the types of equipment you own or have to work with. Roads should be designed for stability as a primary concern, and then constructed using the types of equipment called for by the road design and the environmental setting. Similarly, operators should be used who are experienced with the equipment and with implementing similar design requirements.

The bulk of road reconstruction may consist of vegetation removal and grading performed by tractors on abandoned roads that have been overgrown for many years. As with road construction, however, it is very important to use the proper types of heavy equipment when the more complicated situations are encountered (Table 19). Thus, excavating equipment is often specified for road reconstruction, especially where the old road has been built next to a stream or within a watercourse protection zone (Figure 25). Where stream crossings have partially or completely washed-out, hydraulic excavators may be needed to reinstall upgraded culverts and to place and compact fill. Loaders and dump trucks may be needed for spoil removal where the road is blocked by cutbank failures.

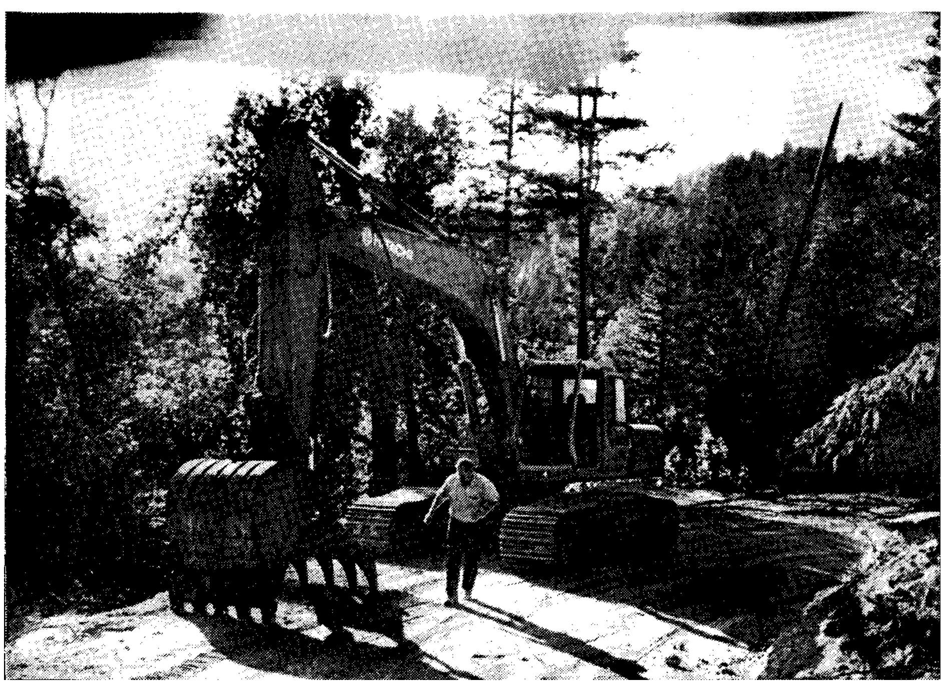


***Figure** 25. Perhaps the most versatile of road building equipment today is the hydraulic excavator. Low impact roads can be built quickly and efficiently using this now-common type of earth moving equipment. Roads constructed exclusively using bulldozers to cut-and-sidecast soil material are best confined to hillslope gradients less than about 35 percent and to areas where incised stream channels are not common.*

Table 19. Settings and equipment combinations suitable for various types of road construction methods.

Generic road type	Hillslope characteristics	Typical equipment types
Sidecast (cut-and-sidecast)	Gentle (<35%); stable, far from streams	tractor; grader; water truck
	Moderate (<55%), stable, far from streams	excavator and tractor, or tractor; grader; water truck
	Moderate (<55%), close to stream	excavator and tractor; grader; water truck
Cut-and-fill (with compaction)	Gentle (<35%)	excavator and/or tractor; grader; water truck
	Moderate to steep (35-55%)	excavator, or excavator and tractor; grader; water truck
Full bench (cut)	All slopes	excavator, dump trucks, some tractor, grader, water truck
Temporary fill (cribbed)	Moderate to steep	excavator and tractor
Reconstruction	All slopes	excavator, tractor; loader; dump trucks; grader

Notes:

CHAPTER V: DRAINAGE

A. Introduction to road drainage

It is impossible to over-emphasize the importance of drainage in maintaining stable roads and protecting water quality. Roads should be designed and constructed to cause minimal disruption of natural drainage patterns. Provisions for two components of road drainage should be included in every road project: 1) road surface drainage (including drainage which *originates* from the cutbank, road surface and fillslope) and 2) hillslope drainage (including drainage from large springs, gullies and streams which *cross* the road alignment).

B. Road surface drainage

Road surface drainage is accomplished by insloping, outsloping or crowning the roadbed. Without adequate cross-slope, the road surface will either pond water, or concentrate runoff down the roadbed and create surface erosion. Roads with springs along the cutbanks are often insloped with an inside ditch, roads with smaller cutbanks or dry cutslopes may be outsloped for most of their length, and some larger roads are crowned to most rapidly drain runoff from their surfaces. For seasonal roads, insloping can occur with or without an inside ditch.

1. Outsloped roads

It is generally recommended that most forest and ranch roads be constructed as single lane (minimum width), outsloped roads with minimal cut-and-fill, where conditions are suitable (Figure 26). These roads are likely to cause the least disturbance and soil movement, create less environmental impact and have lower maintenance costs than other designs. All-season roads built high on the hillside, or wherever the surface can be kept dry, can generally be outsloped. Conditions that might limit road outsloping include, 1) steep road grades (which may make adequate outsloping difficult), 2) winter use of an unsurfaced road (snow or muddy conditions on a steep, outsloped road may be hazardous), or 3) upslope runoff or excessive spring-flow from the cutbank or road bed (which makes an inside drainage ditch necessary).

Figure 26. *Well built outsloped road displaying minimum cut, smooth free draining surface, no outside berm and rolling dips to help disperse surface runqff.*

Even on roads which are outsloped for much of their length, some sections can be insloped to deal with local conditions. For example, short sections of insloping, in combination with an inside ditch, can be used to drain local wet areas. The road can be either insloped or outsloped through stream crossings. Finally, while some wet cutbanks may require the construction of an inside ditch (or French drain) for drainage, the roadbed itself may still be a worthy candidate for outsloping. Outsloping will minimize flows in the inside ditch and reduce the potential for erosion and sediment delivery to the next culvert

On climbing (or falling) roads, the road surface can be drained using rolling dips or waterbars. Rolling dips are smooth, angled depressions constructed in the roadbed (Figure 27). Dips should be constructed deep enough into the road subgrade so that traffic and subsequent road grading will not obliterate them. Their length and depth should provide the needed drainage, but not be a driving hazard.

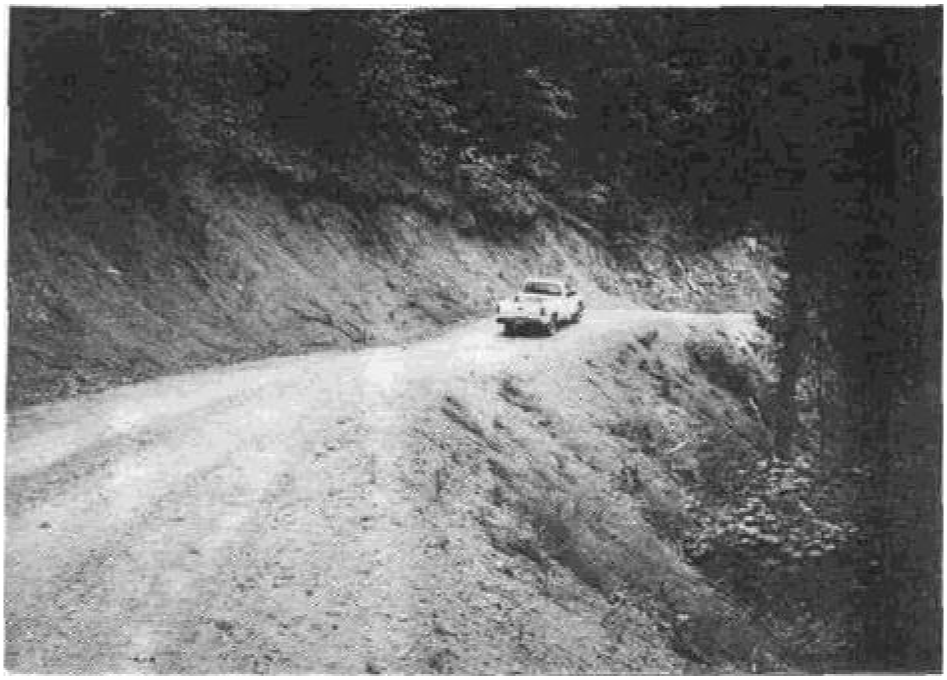


Figure 27a. Rolling dip constructed on a rock surfaced forest road (a). The rolling dip represents a change-in-grade along the road alignment and acts to discharge water that has collected on or is flowing down the road surface.

Figure 27b. A side view (b) shows that the rolling dip does not have to be deep to reverse road grade and drain the road surface.

In general, broad rolling-dips are built at a 30 to 45 degree angle to the road, with a cross grade of at least 1 percent greater than the grade of the road. Some are built nearly perpendicular to the road alignment. They are built with a long, shallow approach on their up-road side and a more abrupt rise or "lip" on their down-road side (Figure 28, Table 10). They are usually used on outsloped roads to drain road surface runoff to the outside of the road, but may be built on either insloped or outsloped roads to drain in either direction. Rolling dips should be placed at intervals frequent enough to prevent road surface rilling and erosion (Tables 3 and 17), yet broad enough to permit uninterrupted vehicle travel. They may be designed and constructed into new roads, or they may be built into older, existing roads that are being reconstructed.

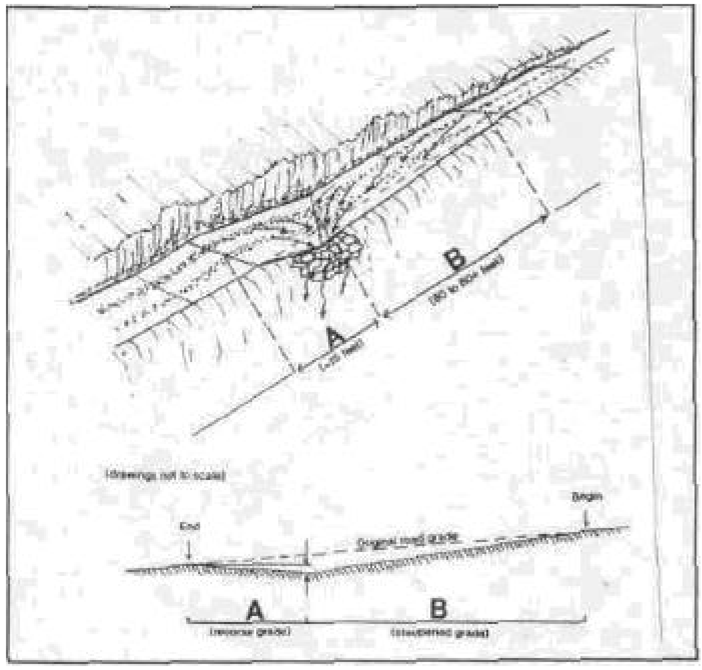


Figure 28. The up-road approach to the rolling dip (B) is several percent steeper than the approaching road and extends/or 60 to 80 feet to the dip axis. The lower side of the structure (A) reverses grade over approximately 15 feet, and then falls down to rejoin the average road grade. It must be deep enough that it is not obliterated by normal grading, but not so deep that it is difficult to negotiate or a hazard to normal traffic. The outward cross-slope of the dip axis should be at least 1% greater than the original road grade so it will drain properly.

Waterbars (also called waterbreaks) can also be used to drain a road surface. These are shallow, abrupt excavated dips or troughs with an adjacent, downslope hump or mounded berm, that are built at an oblique angle across the road. **Waterbars are useful only on low standard seasonal or temporary, unsurfaced roads where winter use will not occur, because traffic easily cuts through the soft berm and fills the adjacent dip.** Waterbars should be constructed at proper spacing according to the grade of the road (Figure 29; Tables 3 and 17). Waterbars are usually regraded (smoothed out) at the beginning of each operating season, and then reconstructed at the beginning of each winter period.

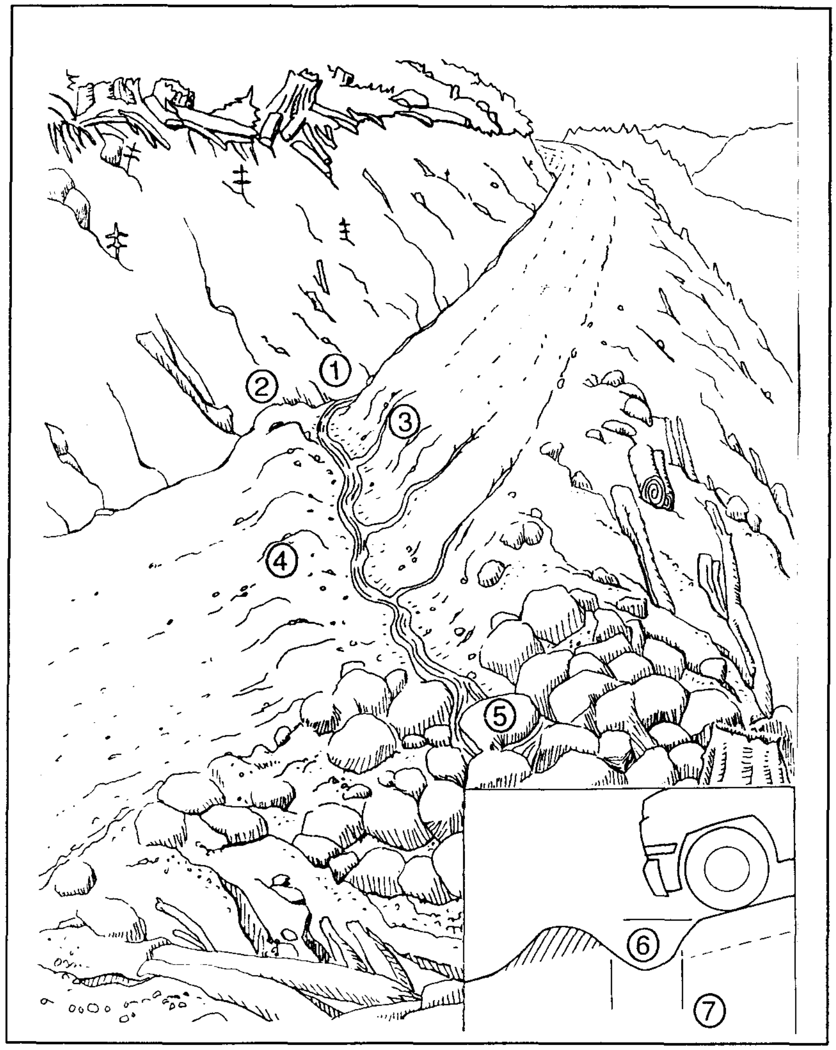


Figure 29. Waterbars are constructed on unsurfaced forest and ranch roads that will have little or no traffic during the wet winter period. The waterbar should be extended to the cutbank to intercept all ditch flow (I) and extend beyond the shoulder of the road. A berm (2) must block and prevent ditch flow from continuing down the road during flood flows. The excavated waterbar (3) should be skewed 30° to the ditch-line with the excavated material bermed on the downhill grade of the road (4). Water should always be discharged onto the downhill side on a stable slope protected by rip rap or vegetation (5). The cross ditch depth (6) and width (7) must allow vehicle cross-over without destroying the function of the drain (B.CM.F., 1991)

Waterbars are high maintenance drainage structures that are prone to failure if not properly built and maintained. Unauthorized winter traffic is likely to break down waterbars and result in serious road surface erosion and water pollution.

On outsloped roads, a narrow berm can be locally constructed along the outside edge of the road to divert road runoff away from erodible fillslopes (Figure 30). This technique of road surface drainage control may be used where road fills are especially steep, erodible or located close to watercourses, such as at stream crossings. Collected runoff can then be funnelled to protected areas or discharged across the fill through a fabricated, sheet metal berm-drain that is located at a designed break in the outside berm. This practice, however, adds a high risk and high maintenance feature to an otherwise low-maintenance drainage design. Unfortunately, repeated annual grading on many wildland roads has created widespread outside road berms that collect road surface runoff and create rill and gully erosion on roads and fillslopes. **Generally, outsloped roads should *not* be built with outside berms.**

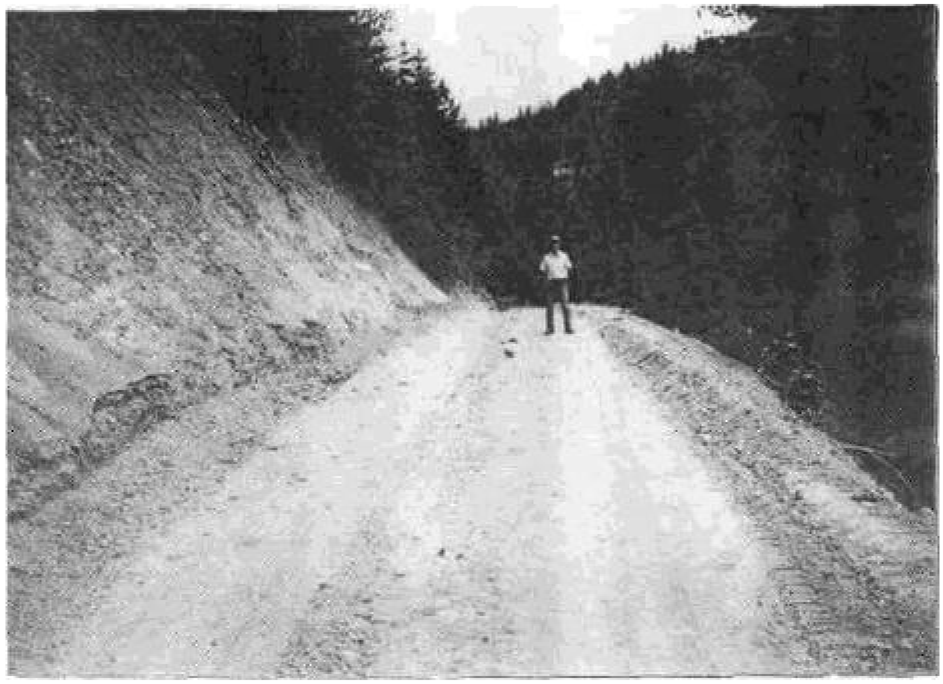


Figure 30. Short road reach where a soil berm has been constructed along the outside edge of the road prism, to prevent surface runoff from flowing over the highly erodible fill. To prevent the road surface from accumulating too much runoff and eroding, the berm can be intermittently breached and a wooden or sheet metal berm-drain used to carry runoff dawnslope past the base of the erodible fillslope.

Open top box culverts can also be used to drain the road surface, but they may fill with soil and rock, are difficult to grade over, and require higher levels of maintenance. Recently, experimental rubber-waterbars have been installed on forest roads in Oregon. These structures are located in the same position and orientation as dug waterbars. Their base is buried into the roadbed, and a thick, stiff rubber flap sticks up above the road surface to capture and direct surface runoff. The flap bends down as vehicles pass over the waterbar and then immediately springs back to deflect runoff. Unlike the dug waterbar, which tends to break down with continued vehicle use, the rubber waterbar should remain functional in traffic. The rubber waterbar will be most useful on rocked roads or on seasonal roads where frequent road grading is not necessary.

2. Insloped roads with ditches

Insloped roads should be constructed only where road surface drainage discharged over the fillslope would cause unacceptable erosion or discharge directly into stream channels, where fillslopes are unstable, or where outsloping would create unsafe conditions for use. It is generally preferable to outslope road surfaces in order to disperse road surface runoff before it has a chance to concentrate.

Insloped roads should be built with an inside drainage ditch to collect and remove road surface runoff (Figure 31). Roads steeper than about 8 percent may be too steep for an inside ditch because of the potential for gullying in the ditch. Inside ditches should also be drained at intervals sufficient to prevent ditch erosion or outlet gullying, and at locations where water and sediment can be filtered before entering a watercourse. "Filtering" can be accomplished by thick vegetation, gentle slopes, settling basins, or filter windrows of woody debris and mulches placed and secured on the slope.

Figure 31. Rock surfaced, insloped road with an inboard ditch. A ditch relief culvert carries ditch/low beneath the road at location "A."

As with outsloped roads, steep insloped road surfaces may be difficult to quickly drain. Rolling dips (for permanent, surfaced roads and seasonal roads) or waterbars (for seasonal or temporary, unsurfaced roads) should be constructed at intervals sufficient to disperse road surface runoff from steep road segments (Tables 3 and 17).

Ditches and culverts need occasional maintenance to operate correctly and to carry the flows they were designed to handle. The most important type of maintenance is annual and storm period inspections which can prevent small problems from growing into large failures. When ditches become blocked by cutbank slumps, they need to be cleaned and the spoil deposited in a stable location. However, excessive maintenance (mostly grading) can cause continuing and persistent erosion, sediment transport and sediment pollution to local streams during storm runoff. It may also remove the rock surfacing.

Ditch relief culverts should be designed and installed at intervals along the road that are close enough to prevent erosion of the ditch and at the culvert outfall 1, and at locations where collected water and sediment is not discharged direcdy into watercourses (Table 20). On new roads, ditch flow should be culverted and discharged into buffer areas and filter strips before it reaches a watercourse crossing (Figure 32). Ditches should neither be discharged directly into the inlet of a watercourse crossing culvert, nor should ditch relief culverts discharge into a watercourse without first directing flow through an adequate filter strip. In addition to installing ditch relief culverts on either approach to watercourse crossings (Figure 32), it is also advisable to consider installing ditch drains before curves, above and below through-cut road sections, and before and after steep sections of the road.

[1] California's Forest Practice Rules do not prescribe the maximum or proper distance between inside ditch relief drains. Instead, they state that adequate drainage must be provided. Indicators of inadequate relief drain spacing include: 1) gullying of the inside ditch, 2) gullying or sliding of the slope below the culvert outlet of a cross drain, 3) direct transport of sediment along an inside ditch to a watercourse, or 4) loss of capacity of culvert cross drains due to filling with sediment.

Figure 32. Where a road approaches a stream crossing (B), ditch flow should be adverted across the road (A, D) and discharged into a vegetative buffer that can filter the runoff before it reaches the watercourse. If the stream culvert plugs with debris or is topped by flood flows, flow will spill over the road at the change-in-grade at location "C" and back into the stream channel (modified from MDSL., 1991).

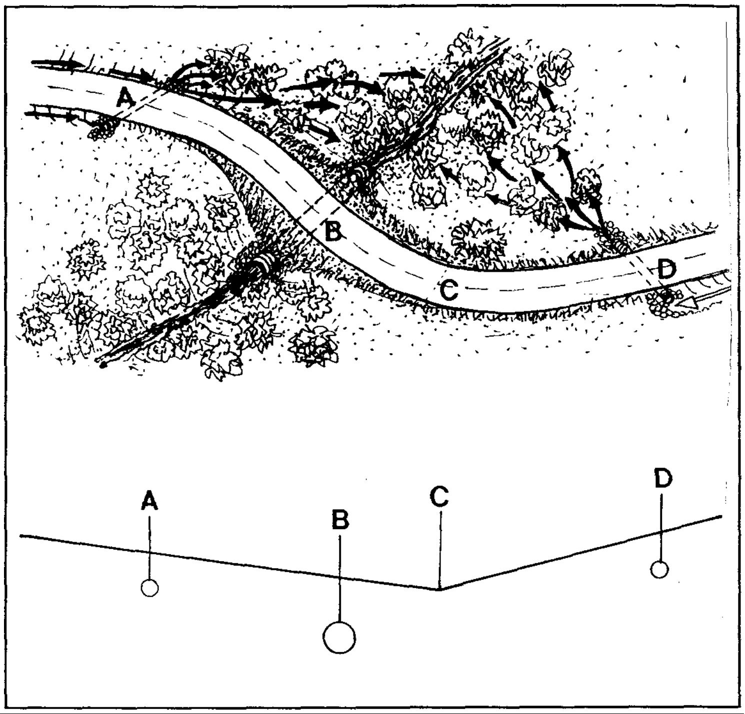


Table 20. Maximum suggested spacing for ditch relief culverts[1] (ft)					
Road grade (%)	**Soil credibility**				
	very high	**high**	**moderate**	**slight**	**very low**
2	600-800[2]				
4	530	600-800[2]			
6	355	585	600-800[2]		
8	265	425	525	600-800[2]	
10	160	340	420	555	
12	180	285	350	460	600-800[1]
14	155	245	300	365	560
16	135	215	270	345	490
18	118	190	240	310	435

[1] Adapted from Transportation Handbook USDA Forest Service, R-6, 1966. Culvert spacing may be too great in locations where ditch runoff is accumulated and discharged onto steep hillslopes that are prone to gullying. Spacings are designed to control ditch erosion, not culvert outfall erosion, and are based on 25-year storm and precipitation rate of 1-2 in/hr for 15 minutes. If less, multiply by the intensity 0.50, 030, etc. If 2-3 in/hr, divide distance in table by 1.50; if3-4 in/hr, divide by 1.75; and if 4-5 in/hr, divide by 2.00. The U.S. Forest Service also publishes abundant information on preventing and controlling gully erosion below culvert outfalls.

[2] Even with stable ditches, ditch relief culvert spacing greater than about 600 to 800 feet is generally not recommended due to the large volume of road surface and cutslope runoff that would be discharged through the culvert and onto lower slopes during peak runoff periods. Culvert outlet erosion may occur with less than 800 feet of contributing ditch line, so observe local conditions to determine the upper limit of acceptable spacing in your area.

If a ditch is capable of transporting and delivering sediment to a Class I or Class II watercourse during a flood event, it can be said to function the same as a Class III watercourse. It has a bed and a bank, and it can transport sediment Ditches which drain directly into watercourse crossing culverts should be treated and protected from disturbance and erosion, just as is a Class III watercourse. Ditch relief culverts should be installed across ditched roads before watercourse crossings so that water and sediment can be filtered before reaching the stream.

Ditch relief culverts do not need to be large, since they carry flow only from the cutbank, springs and a limited length of road surface. **In areas of high erosion and/or storm runoff, minimum ditch relief culvert sizes should be 18 inches, but ditch relief culverts should never be less than 12 inches diameter.** Smaller culverts arc too easily plugged.

Generally, culverts should have a grade at least 2 percent greater than the ditch which feeds it to prevent sediment buildup and blockage. Where possible, ditch relief culverts should be installed at the gradient of the original ground slope, so it will emerge on the ground surface beyond the base of the fill. If not, either the fill below the culvert outlet should be armored with rock, or the culvert should be fitted with an anchored downspout to carry erosive flow past the base of the fill. Culverts should never be "shot-gunned" out of the fill, thereby creating highly erosive road drainage "waterfalls."

A 10 percent grade to the culvert will usually be self cleaning. The culvert should be placed at a 30 degree skew to the ditch to improve inlet efficiency and prevent plugging and erosion at the inlet (Figure 33). The pipe should be covered by a minimum of 1 foot of compacted soil, or to a depth of 30% of its diameter, whichever is greater. Finally, inlet protection, such as rock armoring or drop structures, can be used to help minimize erosion, slow flow velocity and settle-out sediment before it is discharged through the pipe (Figure 33).

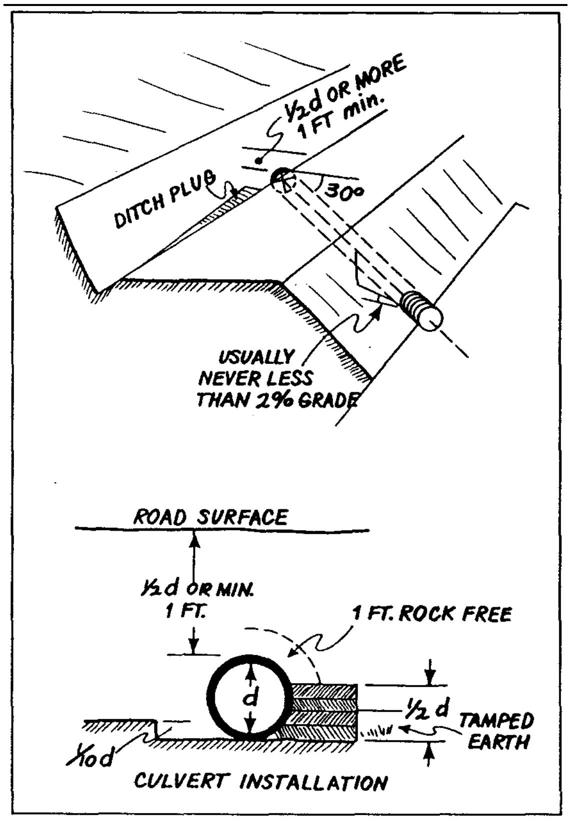


Figure 33. *The elements of a properly installed ditch relief culvert. The culvert is angled at about 30 degrees to the road alignment to help capture flow and prevent culvert plugging or erosion of the inlet area. It is set at the base of the fill (ideally) or with a grade slightly steeper than the grade of the contributing ditch (but never with a grade less than 2 percent) (USDA-SCS, 1983).*

C. Hillslope drainage (stream crossings)

Where a road crosses a natural watercourse, provision should be made to carry the water under the road. Streams can be crossed with bridges, culverts or fords. Culverts are the most common stream crossing structure. Bridges are best for large streams or where there is a lot of floating wood and debris in flood flows. Bridges also have less effect on fisheries than other methods. Fords work well on small to medium sized streams where there is a stable stream bottom and vehicle traffic is light. Compared to a culverted fill, they have the advantage of little fill to wash out during flood flows. Unless wet fords are constructed of poured concrete, they are less desirable in high traffic areas because continued disturbance to the streambed can cause persistent downstream turbidity and fine sediment pollution problems. Dry fords on seasonal roads can often be installed and used with minimal impact to the channel system.

1. Legal requirements

All private landowners constructing temporary or permanent stream crossings need to obtain proper permits and follow applicable laws and regulations of state and federal agencies. Prior to conducting road building or timber operations, or to modifying the bed or banks of a stream channel for *any* purpose, it is important to determine the legal requirements of your work.

Under the provisions of section 1603 of the Fish and Game Code, ***any activity that would result in the diversion or obstruction of natural stream/low, or in physical modification of the bed or banks of a stream or lake, is unlawful to perform without first formally notifying the Department of Fish and Game.*** The Department of Fish and Game will act on your 1603 proposal within 30 days (or sooner), and may request a field Visit to the site and/or propose measures deemed necessary to protect fish and wildlife. Permanent or temporary stream crossing structures, fords, rip-rapping or other bank stabilization measures, culvert installations, bridges, or skidding across temporary crossings are some of the projects which are subject to the 1603 notification process (Appendix B).

Forestry operations and road activities near watercourses are also subject to the California Forest Practices Act and to rules and regulations developed by the State Board of Forestry and administered by the California Department of Forestry and Fire Protection (Appendix C). These apply to any forest operation involving commercial wood products. The rules include culvert sizing requirements, requirements for removal of temporary stream crossings, limits on equipment operations near stream channels, road construction standards, and a variety of other road building and erosion control requirements. Information on the Forest Practice Act and Rules can be obtained from Ranger Unit offices of the California Department of Forestry and Fire Protection.

Federal and state water pollution regulations are administered and enforced by the California Water Resources Control Board, through their Regional Water Quality Control Boards. Information about requirements pertaining to road building work can be obtained from the Regional Water Quality Control Board with jurisdiction for your area. A wrong choice in stream crossing method can result in major damage to both the immediate site and to downstream water quality. There are strict legal requirements for protecting water quality. ***Stop-work orders, clean up and repair orders, and penalties for pollution can delay your project and be very expensive. Do it right the first time!***

Ask your local California Department of Fish and Game warden, a forester from the California Department of Forestry and Fire Protection, and your Regional Water Quality Control Board inspector for assistance and information about requirements for your project. Prevention is always the best course of action.

2. Stream crossing design

Classifying the stream (Class I, II, III or IV) and the road (temporary, seasonal or permanent all-weather) is the first step in defining the type of crossing to be installed. Stream crossings should be designed for adequate fish passage (where fish could be seasonally present), minimum impact on water quality, and to handle peak runoff and flood waters. Stream crossings can be classified as either "permanent"[2] or "temporary." There are three basic subcategories of both permanent and temporary stream crossings: 1) bridges, 2) fords, and 3) culverts. Culverts include not only the traditional corrugated metal pipe (CMP), but also "Humboldt" log crossings, and other temporary structures that pass streamflow through the road fill.

The type of crossing facility selected will depend on a number of factors. Each of these elements should be considered before selecting the final design or location for the stream crossing installation. Design considerations include:

1) whether or not fish use the channel at the crossing site,
2) whether the crossing will be temporary (used for only a single entry) or permanent (to be used for a number of years),
3) the type of vehicles that will use the crossing,
4) the slope, configuration and stability of the natural hillslopes on either side of the channel (soil foundation conditions),
5) the slope of the channel bed,
6) the orientation of the stream to the proposed road,
7) the expected 50- or 100-year flood discharge (i.e., stream size),
8) the amount and type of sediment and woody debris that is in transport within the channel,
9) the installation and subsequent maintenance costs for the crossing,
10) the expected frequency of use, and
11) permits and other legal requirements.

These and other site-specific factors play a role in determining the best crossing location and most suitable type of stream crossing to be used.

[2] There is really no such thing as a "permanent" culverted stream crossing. Culverts are subject to a variety of processes which guarantee their eventual failure unless they receive periodic and storm maintenance, and they are replaced and rebuilt at the end of their normal life span. Metal culvert pipes have a limited life span and will eventually wear down and fail. In addition, since culverts are designed to pass a "design flood," a larger flood will eventually occur which exceeds culvert capacity and washes out the stream crossing.

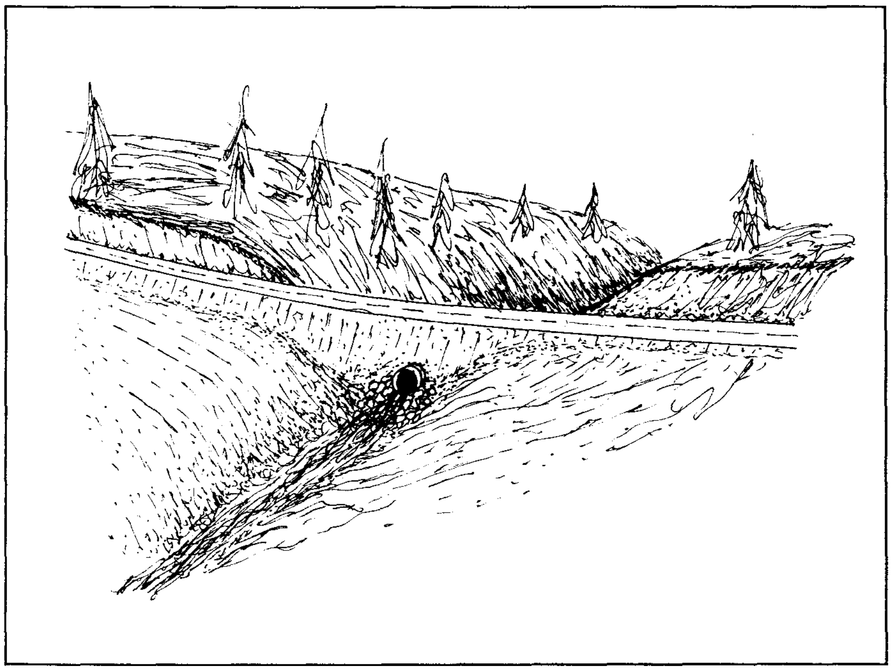
3. Fail-safe and "fail-soft" drainage designs

Culverted stream crossings are naturally susceptible to failure. That is why it is somewhat of a misnomer to call culverted stream crossings "permanent." In reality, a fill crossing is really an earthen dam, placed across a stream channel, that has a small hole (culvert) in the bottom. Plug the hole with sediment, vegetation or wood, and the dam will wash out. That's why culverted crossings need to be properly designed, constructed and maintained to prevent loss of the fill and discharge of large volumes of soil into the stream.

Washed-out stream crossings are a common occurrence on abandoned, poorly maintained and/or improperly designed forest and ranch roads. However, culvert plugging can result in much more damage than a washed-out stream crossing fill. If flow from a plugged culvert is diverted down the adjacent road (instead of flowing over the fill and immediately back into the stream channel), the diverted streamflow can create large gully systems or trigger landslides as it flows over nearby unprotected hillslopes.

Stream crossings with a **high diversion potential (DP)** occur wherever the road climbs through the crossing and one approach slopes away from the stream crossing (Figure 34). If the culvert plugs on a crossing with a high DP, backed up flood waters will be diverted down the road alignment (Figure 35). If the crossing has no DP, backed up flood waters will flow onto the road surface, over the fill and back into the natural channel. The fill may be washed-out, but streamflow is not diverted out of the channel and onto adjacent, unprotected roads and slopes.

*Figure **34a.** Stream crossing with diversion potential (a) and with no diversion potential (b). In Figure 34a streamflow would be diverted down the road toward the right side of the picture.*



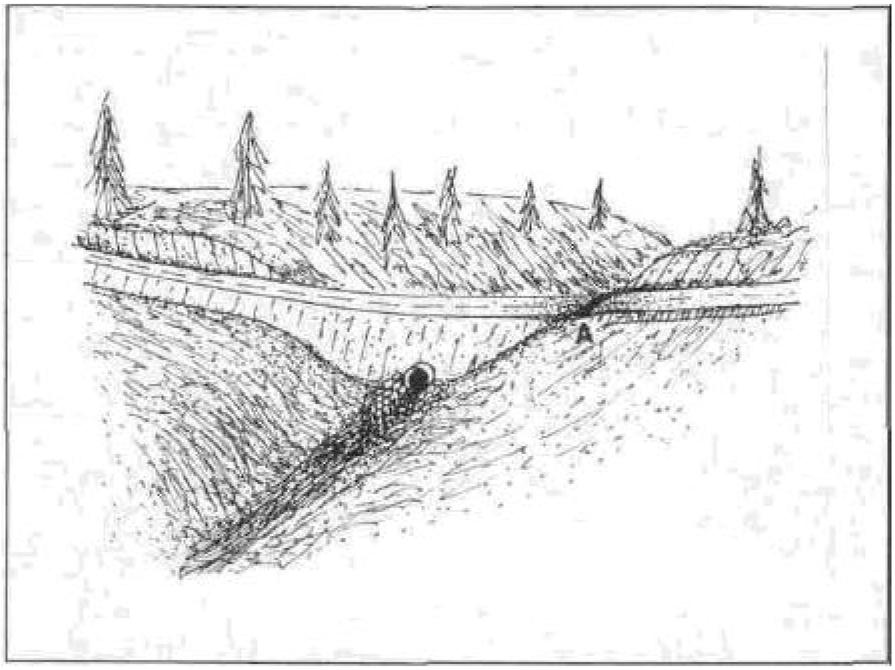


Figure 34b. *In Figure 34b flow would reach the road surface and flow back into the channel at location "A," where the road changes grade.*

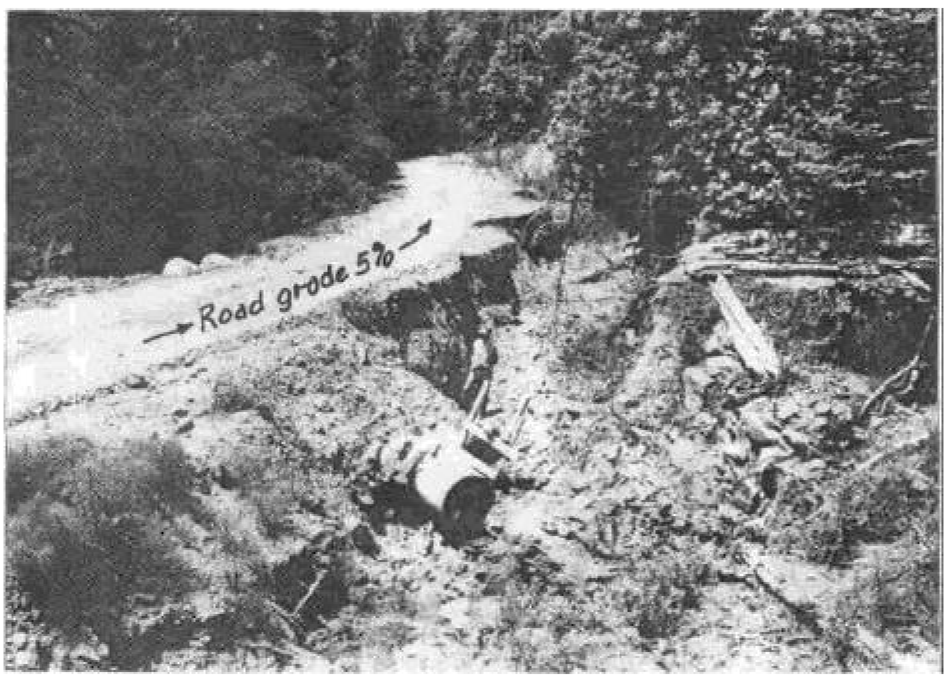


Figure 35. *Double culvert stream crossing showing the result of a stream diversion that occurred during a winter storm. The road slopes to the distance at about 5 percent, so when the culverts plugged with debris, water flowed down the inboard ditch and created the large diversion gully.*

A very large number of existing stream crossings on private forest and ranch land have been constructed with a high diversion potential (Figure 36). During road reconstruction, these high DP crossings should be corrected by constructing a broad rolling dip over or immediately down-road from the fill. New stream crossings should be constructed to prevent stream diversion of flood overflow if the culvert were to become plugged. This can be done by designing the road to "dip" into and out of the stream at the crossing site (a dipped crossing), or by installing a broad rolling dip on the down-road side of the crossing, so that flood overflow will be directed back into the natural stream channel (Figure 37). **Stream crossings on all newly built or reconstructed roads should not be constructed in a manner that gives any opportunity for future stream diversion.**

Stream crossings with no diversion potential are said to be designed as **"fail-safe"** because a dip in the road grade prevents flood flows from ever flowing down the road. Fail-safe stream crossings are also said to be **"fail-soft"** if the dip in the road bed is located over the edge (not the center) of the fill, so that erosion from an overflow event will be less likely to erode and wash out the entire fill.

Figure 36. *Steeply climbing road crosses a stream channel without changing grade, creating a crossing with a high diversion potential.*

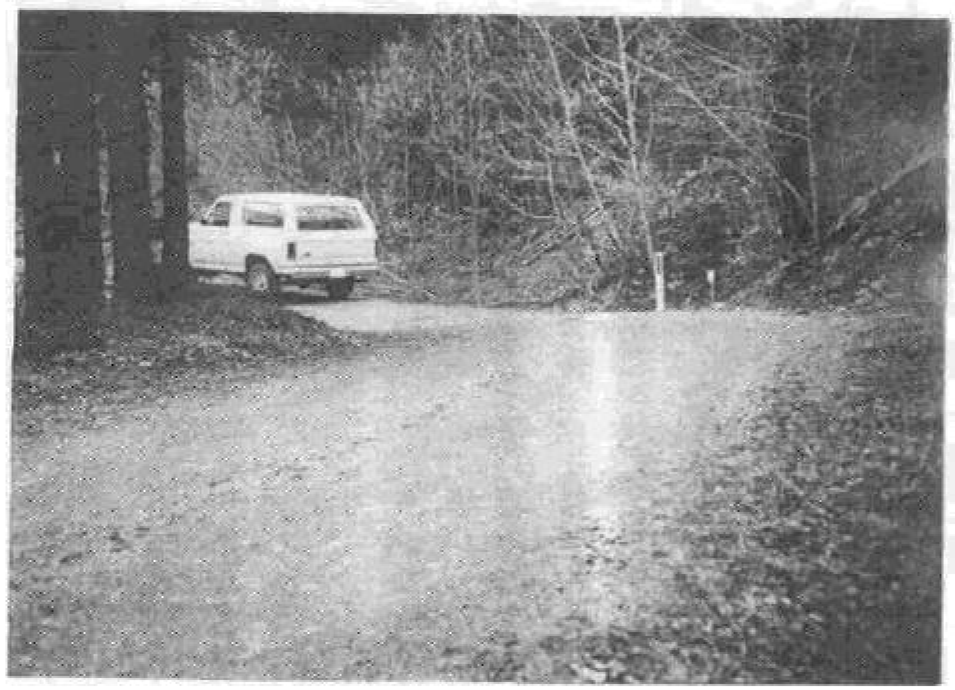


Figure *37. A gradually climbing road changes grade over the stream crossing, thereby eliminating the possibility for future stream diversions.*

4. Stream crossing culverts

To function properly, culverts should be installed at a stable grade (preferably at or slightly below the bed of the original stream channel). It is best for the road to cross at right angles to the stream channel, but regardless of the road alignment, the culvert should be placed parallel to the natural channel so that the inlet will not plug and flow from the outlet will not erode either of the channel banks (Figure 38).

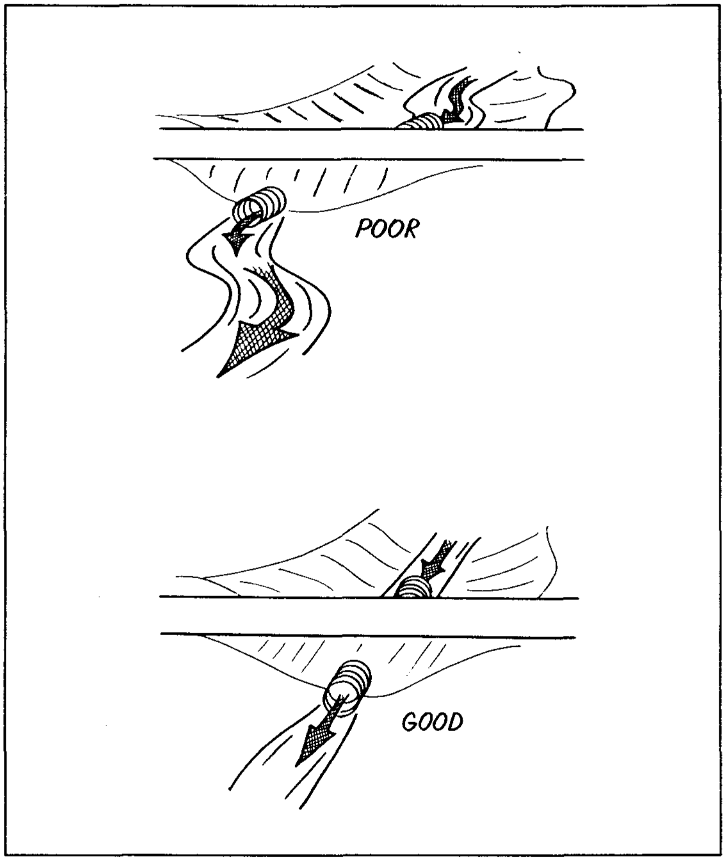


Figure 38. *Culverts should be aligned with and placed in the bed of the natural channel so that flow enters and exits the culvert without having to turn (USDA-SCS, 1983).*

On fish-bearing streams, fish passage must be designed into all watercourse crossings (Figure 39). Most obstructions can be prevented if the potential for fish passage is recognized during road planning. Culverts should be placed at or slightly below grade (so fish don't have to jump up into the culvert). If flows are rapid, the culvert diameter should be increased and the culvert grade reduced. Resting pools should be designed immediately below and above the culvert. Maintaining a stable stream bottom through the culvert-influenced area is essential. Avoid installation of round culverts where fish passage might be difficult. Instead, use either open arch culverts or bridges. **In order of decreasing desirability, bridges, structural plate arch culverts, corrugated pipe-arches, and corrugated round metal culverts can be used for fish passage.** Bridges should be used on all larger, faster streams (Figure 40).

Figure 39. Incorrect culvert installation can impede or prevent fish passage through a stream crossing. Culvert conditions that block fish passage include: A) water velocities too great, B) water depths too shallow, C) insufficient resting area or jumping pool depth at culvert outlet, and D) culvert outlets that are too high above the streambed (Furniss, et.al., 1991).

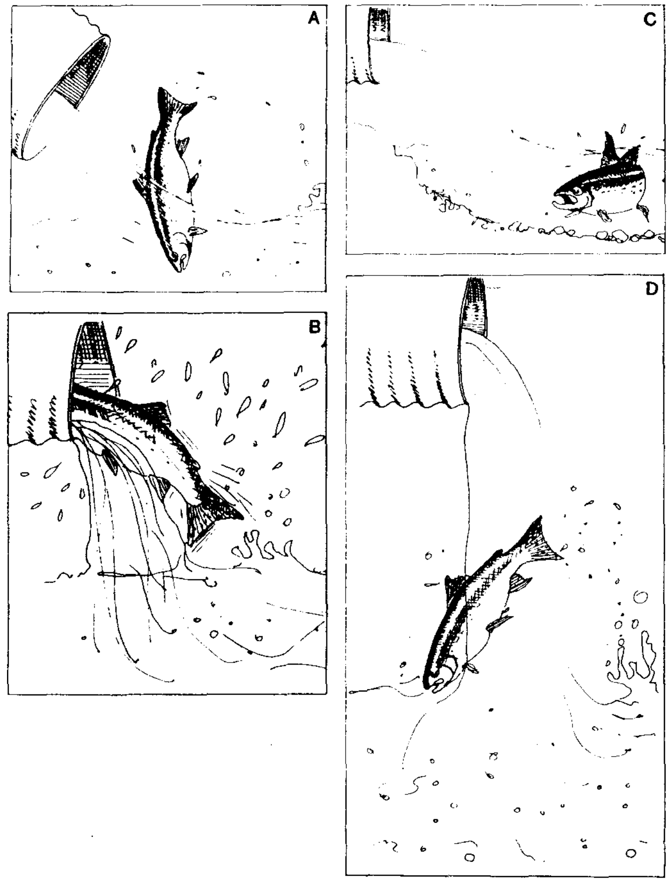
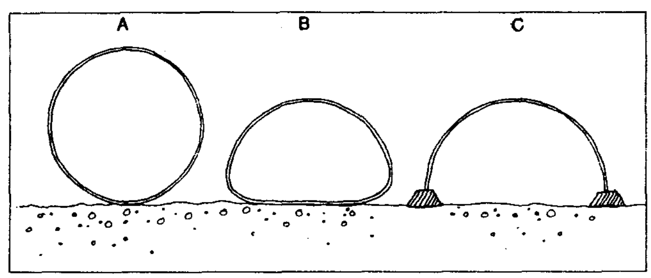


Figure 40. Three common types of stream crossing culverts are used in forest-land and ranch-land road construction: A) round culvert, B) pipe arch culvert and C) plate arch "culvert." For stream crossings where fish passage must be accommodated and a bridge cannot be installed, plate arch culverts are preferred. Round culverts are the least preferred culverting method where fish passage is important.



Debris control structures (trash racks) at culvert inlets, and energy dissipators at culvert inlets and outlets, are key components of stable culvert design (Figure 41). The design of these protective structures has been varied, and there are as many successful designs as there have been failures. Debris control is best obtained by some type of grate or "filtering" structure of inclined poles built across the channel just ***upstream*** from the culvert inlet Creativity and experience can be used to develop a successful design. Drop inlet "trash racks" have proven to be effective in trapping debris without allowing the culvert to plug. If constructed incorrectly, wooden crib boxes built around the culvert inlet can become clogged with debris and plug the culvert, or significantly reduce its capacity to pass flood waters. The most common problem with trash racks placed over the culvert inlet is that small debris is often trapped rather than being allowed to pass through the culvert. This small debris can clog the trash rack and actually cause the inlet to plug.

Figure 4la. *Trash racks at culvert inlets and energy dissipation at culvert outlets are methods of preventing erosion of the stream crossing fill. The most effective trash rack is one placed across the channel just upstream from the culvert inlet.*

Energy dissipation (rock armor is most common) may be needed to prevent high velocity culvert flows from eroding the channel bed or banks at the culvert outlet. Rock should be sufficiently large to resist erosion and transport. If the culvert outlet emerges mid-fill, a downspout or flume will be needed to carry streamflow down past the base of the fill and to the natural channel.

Flow capacity is one of the most important factors in stream crossing culvert design. Culverts need to be large enough to meet flood-stage requirements, not just normal flows. Stream crossings to be built as a part of forestry operations are now required to pass at least the 50-year flood flow for that channel, even if they are to remain in the channel through only one winter season. However, even a 50-year design does not mean that a culvert will not fail (Table 21). Woody debris and sediment transported down a stream channel can also substantially increase the risk and likelihood of culvert plugging and failure. Stream crossing design should account for the possibility of culvert failure from both overflow and from plugging.

The Rational Method is one simple technique commonly used for estimating flood discharges from small watersheds. This method for estimating the 50-year flood flow, and for determining the appropriate culvert size, is included in Appendix A.

Except for the very smallest of crossings, it is generally <u>not</u> sufficient or adequate to estimate (guess) culvert sizes for stream crossings along forest and ranch roads. Most field personnel have little personal experience or expertise with which to correctly estimate or visualize a 50-year flood flow, and many stream channels may no longer display evidence of the most recent large floods, which may have occurred more than a decade ago.

Figure 4 Ib. *Limbs and branches floating down the channel are caught before they can plug the culvert inlet.*

Figure 41 c. *Culvert trash racks which are constructed right over or against the culvert inlet should be avoided because they can plug and, in turn, prevent streamflow from entering the culvert inlet. Culverts that are not set into the bed of the original channel and would discharge runoff onto the road fill need to be extended with an elbow and full round culvert extension, or with a flume (in this case a half-round culvert) past the base of the erodiblefill.*

Culvert length should also be estimated so that correct quantities of pipe will be available on the job site when stream crossings are being installed. Culvert length can be estimated based on the slope of the stream channel/hillslope and the designed width of the road. A procedure for determining the correct length of culvert needed for stream crossings or ditch relief drains is outlined in Appendix E. Culverts that are too short for the crossing cause erosion of the fill and severe sediment pollution in the stream channel.

Figure 41d. *Culverts and flumes carry high velocity stream flow and outlet areas often need to be protected against erosion by the use of rock riprap .*

Table 21. Risk of Hows exceeding flood design for a culvert[1]	
Planned useful life of road	Risk of exc eeding 50-year flood flow
1	1%
5	8%
10	18%
15	27%
20	35%
252	40%
30	45%
35	51%

[1] *WDN.R. (1982)*

[2] *For example, if you plan on using a road for 25 years before closing or reconstructing it, there is about a 40% chance that pipes desig ned/or a SO-year flood along that road will overflow in that time period. Designing for a 100-year flood flow would reduce the risk of failure to about 22%. These figures do not account for plugging by floating organic debris, which would likely increase the risk of plugging and failure considerably for some streams. If you feel these risks are too high, use a larger culvert.*

5. Bridges

Bridges usually have less an environmental impact than culverted stream crossings. They provide much better clearance for extreme floods and floating debris, and bridges are the ideal crossing structure for fish passage requirements. The cost of portable bridge installation is now highly competitive with the installation of medium to large size culverted (filled) stream crossings. For temporary crossings, the quick installation and removal of reusable bridges makes them the method of choice for many crossings that would otherwise require extensive filling and re-excavation.

Bridges may be temporary or permanent. Temporary bridges can be constructed across a stream channel, and then removed upon the completion of operations. Because little soil is disturbed in or along the stream channel, the crossing site can easily be returned to its original condition. Railroad flatcars are the most common, low-cost alternative to conventional bridge construction used for forest and ranch roads. They can also be easily hauled on low-boy trailers from site-to-site and require little preparation prior to installation (Figure 42).

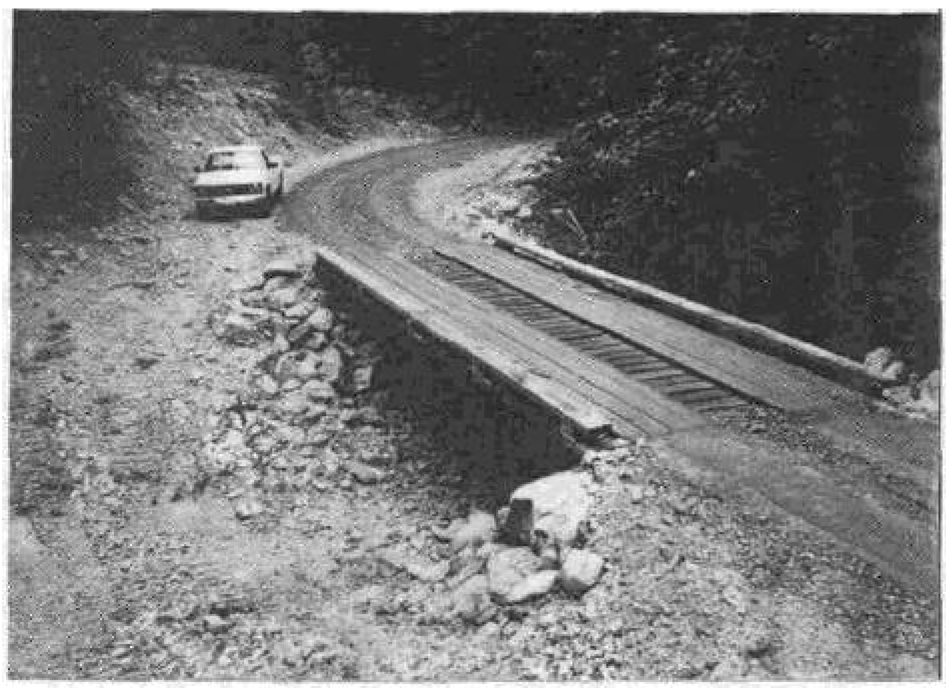


***Figure** 42. Low cost railroad flatcar bridges can be used for temporary crossings of incised stream channels, or they can serve as permanent watercourse crossings.*

Railroad flatcars can also be left in-place and used as permanent bridges. The bridge abutments may be made more permanent by the use of precast or poured concrete supports. Other permanent bridges can be made out of log stringers (large diameter logs extended across the stream channel) or steel I-beams with a driving surface and supporting mechanism. **Bridges used for hauling and vehicle traffic require an adequate engineering design** (Figure 43).

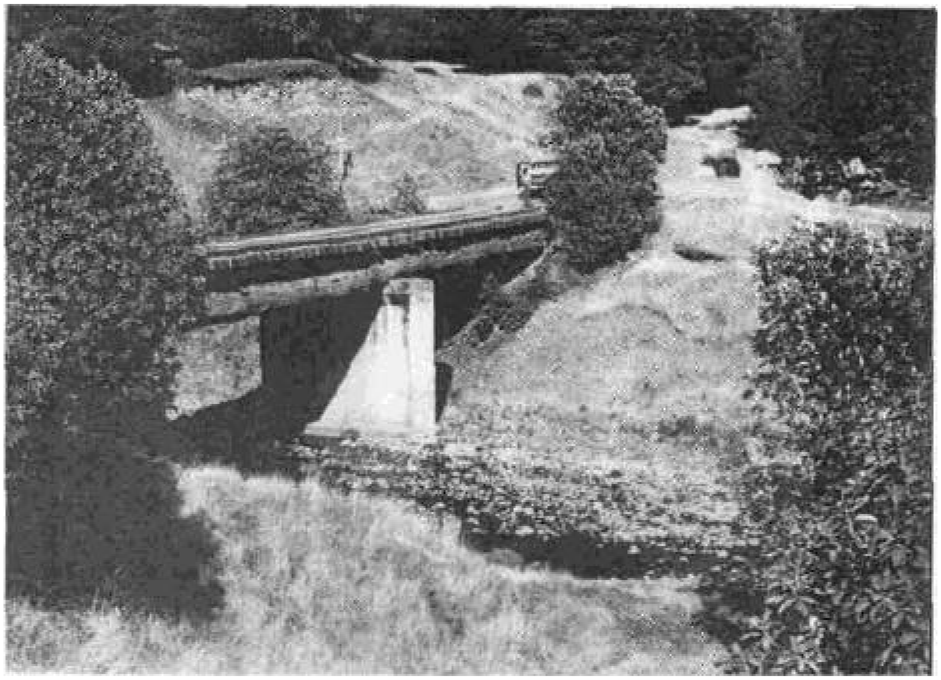


Figure 43a. *Log stringer bridges and railroad flatcar bridges can span •wide channels if they are supported with mid-channel piers.*

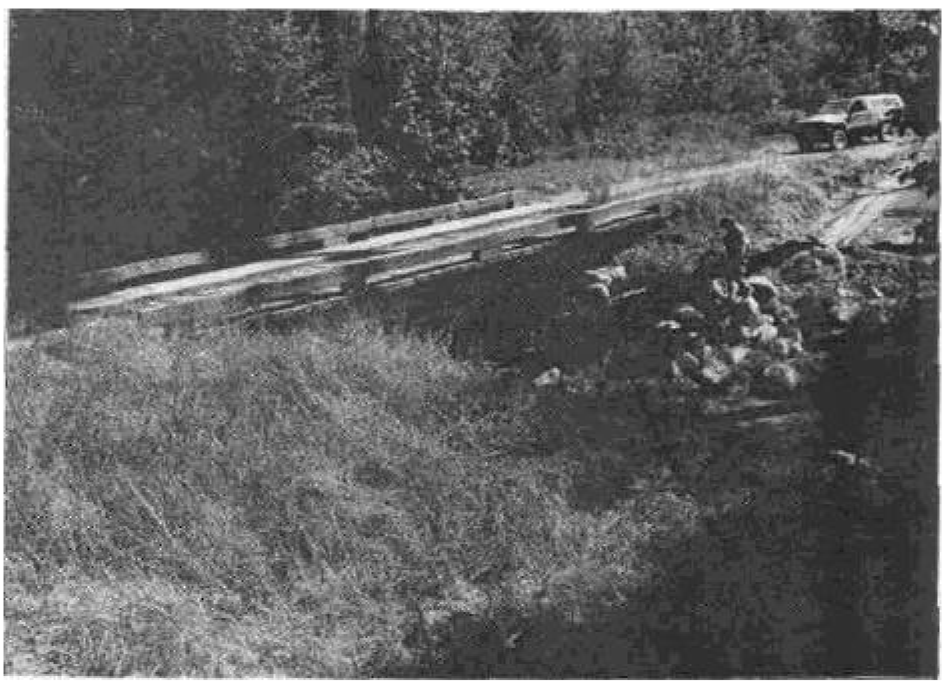


Figure 43b. If possible, it is usually best to span the channel without using center supports and to build abutments well out of the flood zone of the channel. Abutment areas exposed to flood waters should be armored to protect them against erosion. In practice, abutments should be built up and out of the flood zone so they do not restrict channel flood capacity.

Not every stream crossing is equally suited to bridge installation. Generally, bridges should be installed at right angles to the channel with enough clearance beneath the structure to pass the design flood flow (including organic debris). Incised stream channels with relatively flat or low gradient approaching slopes are well suited to bridges. Because bridges are generally straight and fairly narrow, all the turning needed to cross the channel must be incorporated into the approaching road segments. Thus, deeply incised stream channels with steep sideslopes may require extensive excavation (and endhauling) of the approaches before a bridge can be installed across the channel. One method of avoiding some excavation is to install dual, side-by-sidc flatcar bridges so that some vehicle turning can be performed on the deck of the bridge, or to utilize special construction techniques which allow some turning on the structure (Figure 44).

Figure 44. This railroad flatcar bridge has been structurally modified to allow for some truck turning on the bridge deck. Deeply incised stream channels with steep sideslopes would require extensive hillslope excavation if a straight approach was utilized. The underside of this bridge can be seen in Figure 65.

The simpler, less expensive bridges are usually less than 100 feet long. For example, railroad flat cars generally come in standard lengths of about 55 feet and 90 feet. It is important to be sure the bridge is able to support the design loads that will be passing over the road. Longer bridges may require added superstructure supports, or a center pier to support the extra length (Figure 45). Where such complications are present, an engineer should be consulted before fabricating a bridge structure.

Figure 45. It is important that all bridges used to transport vehicles and equipment be properly designed or evaluated by a structural engineer before they are put into use. This large, reinforced bridge was fabricated from four railroad flatcars with a center pier support that can be folded up under the bridge during winter flood flaws.

6. Fords

Fords work well on small to medium sized streams where there is a stable stream bottom and traffic is light. However, "construction" of fords and other unimproved stream crossings on well traveled roads should be avoided where water is flowing because of their potential to impact water quality. In certain situations, where flash floods, high seasonal flood peaks or floating debris are problems, fords may be a practical answer for crossing a poorly incised, shallow stream.

Fords of live streams, called "wet fords," are typically composed of streambed gravels, fill, or concrete structures built in contact with the streambed so that vehicles can cross the channel (Figure 46). If possible, a stable, rocky (or bedrock) portion of the channel should be selected for the ford. Fords can be made of permeable trench drains of coarse cobbles and boulders. Low summer flows seep through the fill, and high water discharges flow over the top. During extreme events, however, the ford may be completely washed-out. Permeable fords may be a barrier to migrating fish and installation will require approval by the Department of Fish and Game.

Paving fords across live streams may be necessary to maintain water quality if there is to be regular traffic. Paving consists of a concrete, slightly dish-shaped slab across the watercourse, and a discharge apron or energy dissipator on the downstream side to prevent scour during high flows. The structure should be designed to pass both sediment and debris during high flows. Unfortunately, concrete fords are often plagued by scour around their edges, leaving the ford elevated and impassable. Ford structures are sometimes even moved downstream by large flood flows.

A ford crossing is vulnerable to erosion and can create pollution from several sources. High traffic levels and/or high water flows can cause erosion of both natural and artificial streambed materials. Material placed in the stream or moved about by vehicle traffic can create a barrier to fish migration. Deep water crossings can cause oil products to be released from vehicles as they pass through a wet ford. Streams with high stream banks require the excavation of substantial ramps to get vehicles down to the streambed. These through-cut ramps are often sites of substantial surface erosion and rilling that enters the stream during periods of winter rain.

Figure 46. *Wet ford on Class II perennial stream. Clean rock aggregate has been imported for the travelling surface and coarse rock armor protects the outer edge of the road bed. It is important that rock aggregate used in a ford be large enough to resist transport during winter flows. Fords should not be used if high winter flows would cut off access to inspect and maintain drainage structures further out the road.*

On small, poorly incised, ephemeral or intermittent streams a ford may be needed if there is insufficient channel depth to install a culvert. In fact, a rock lined rolling dip with a rock apron face is generally desirable to permanent culverts on these swales and small watercourses. Fords have the advantage, over culverted fills, of never plugging.

Fords on small streams should be rock armored to prevent erosion of the road surface and fill during periods of runoff. The fill face on the downstream side of the fill can either be protected with rock armor or fitted with a large overside drain (berm drain) to prevent erosion. **Unimproved fords, which consist of a stream channel that has been filled with a substantial quantity of soil and left unprotected by armor or surfacing is a hazard to water quality and should not be constructed.**

7. Temporary stream crossings

Temporary stream crossings are used to provide short term access to an area. Temporary crossings should be installed wherever a proposed temporary road crosses a Class I, II, III or IV watercourse. Any stream channel or water source that would be fitted with a drainage structure on a permanent road should receive a temporary drainage structure on a temporary road. The structure should be capable of passing the expected discharge of the channel during the season(s) that it is to remain in place. **If a stream crossing used for forestry operations is to remain in-place after October 15, it must be designed and constructed to pass flood flows from the 50-year runoff event.** Specific techniques for constructing temporary stream crossings are discussed in Chapter VI.

For temporary roads, only temporary crossings are acceptable. Dry fords that are removed following operations are appropriate for dry channels. For live streams, a more substantial crossing is needed. They can be constructed of a variety of materials, including: culverted fills; logs (Humboldt crossings); combinations of logs and pipes; straw bales over pipes and logs; and temporary log or railroad flatcar bridges. Where channels are wet or incised, temporary culverts, temporary log fills or temporary bridges should be used. Log fills (with or without culverts) and portable bridges can often be installed, used and removed with little damage to the stream banks or channel bed.

It is important that the original base level of the stream channel be maintained when a temporary crossing is removed following operations. For this, a "marker" consisting of several inches of straw placed in the bed of the channel is often used to mark the natural channel bed ***before*** any logs or fill is placed in the channel. Re-excavation of the crossing is then relatively simple.

A special category of temporary stream crossing is the low water crossing that is often installed to provide for summer vehicle traffic across large perennial streams during summer low flow conditions (Figure 47). These crossings are typically composed of streambed gravels that have been ramped up on both approaches to the low flow channel with one or more culverts used to carry streamflow. Only clean gravels are used in its construction and no new soil or fine sediment is introduced into the channel. The low flow crossing and culverts are then removed prior to the first fall rains which would raise flows in the river. Fish passage should be considered and designed into the low flow crossing so that juveniles and adults can pass through the structure. A temporary flatcar bridge may be required in some settings.

Figure *47. Summer low-water crossing of a Class I perennial stream. Coarse, clean streambed material has been used to ramp up over the flowing water. Two culverts have been installed at water level to allow for uninterrupted flow and the migration of young fish. A temporary bridge crossing should be used where migrating adult fish need to pass beneath the crossing. Low water crossings should be removed before the first fall rains.*

Notes:

CHAPTER VI: CONSTRUCTION

A. Introduction to construction

The construction phase of a road project is when planning and design decisions are carded out on the ground. To achieve the intended road standard, and to result in minimal impact to the environment, each phase of road construction should be carried out according to the formulated plans. Poor execution of plans, no matter how well designed, can result in a poorly constructed road that causes serious impact to the watershed and environment Such substandard results are most often caused by untrained supervisors or unskilled operators. Thus, the skill and experience of supervisors and equipment operators selected to complete the road project will play a large part in determining its success.

Plans and designs may need to be modified during construction as changing conditions are encountered in the field. Minor changes in the proposed work can be accomplished in the field by experienced supervisors and equipment operators. However, substantial changes in road alignment or in road and drainage design should only be made by qualified personnel.

B. Timing

While planning, design and field reconnaissance work can be conducted at any time of year, the timing of each phase of road construction is critical to a successful project. **Roads should be constructed during the time of year when the best results can be achieved with the least damage to the environment** (Table 4). The time varies when each of the activities (clearing, grubbing, burning, excavation and grading, compaction, stream crossing installation and surfacing) can best be conducted. For example, scheduling road building activities in steep slope areas for the drier months can be an effective landslide control measure.

Clearing (cutting and removal of trees and brush from the right-of-way) can be performed anytime weather permits ground crews to cut the vegetation and equipment to pile or yard it to a storage site. Often, felling crews will cut vegetation along the alignment up to a month before equipment is on-hand to remove the material. Yarding results in soil disturbance and should be limited to reasonably dry soil conditions when rain storms are unlikely. Likewise, grubbing (the removal of organic material from the soil surface, including stump removal) should only be performed when the threat of erosion from the disturbed areas is minimal.

Grading (the excavation and creation of the road bench) creates large expanses of bare soil, and should therefore be performed only during dry spring, summer or early fall conditions. To achieve proper compaction of fill materials used in stream crossings, landings, and along cut-and-fill road benches, most soils will require adequate moisture. Rocky, coarse-textured soils may be placed during relatively dry conditions. Overly dry or very wet, fine textured soils often cannot be compacted enough to produce the soil strength needed to support loaded trucks or to remain stable on steep slopes. If the soils are too wet, they should be allowed to dry, and if they are too dry, they should be watered to achieve adequate compaction. Local problem *areas* are likcJy to be encountered that will need to be treated by drying or watering. An engineer or geologist can recognize improper soil moisture conditions by using simple field tests.

The timing of stream crossing installation is critical to maintaining and protecting water **quality.** Timing is also important to fisheries in many watersheds. Work should be performed as quickly as possible during the dry period of summer, when streamflows are at a minimum (or the channel has dried up) and there will be minimal soil disturbance and risk of sedimentation.

All road construction activities, including the installation of stream crossings and erosion control work, should be completed before the onset of the rainy period (October 15 for forestry operations). Final grading and proper installation of road drainage structures are critical to keeping erosion from the new road to a minimum during the first winter. Likewise, all temporary stream crossings should be removed and all erosion control measures installed before the winter begins. There are additional rule requirements in effect for forestry operations conducted anytime during the winter period. These include developing a "winter period operating plan" that includes the details of proposed landuse and erosion prevention activities. For example, the plan may require all bare soil areas be adequately drained and protected with suitable erosion control measures concurrent with the conduct of timber operations.

C. Clearing and grubbing

The road centerline, or the cut and fill staking, should be marked on the ground prior to clearing. The upslope and downslope boundaries of the right-of-way should also be flagged or staked to mark the limits of vegetation removal for work crews and equipment operators who will be performing the clearing. This will help prevent over-clearing.

Trees and other large vegetation should be felled and bucked. In addition to right-of-way clearing, hazardous snags and unsafe trees should also be felled at this time. **Trees and shrubs** should **be left growing at the base of the proposed fillslopes, and the right-of-way should be kept** to **the minimum width necessary for the planned use of the road.**

During grubbing of the surface, stumps should be removed from within the road prism and anywhere fill or sidecast material will be deposited (Figure 48). **Mixing stumps and other vegetative debris into the road fill should *always* be avoided** because the voids which form when the wood decomposes reduce the stability of the fill. Fine slash and small limbs are usually not a problem, but all chunks, logs and slash over approximately 3 inches in diameter and 3 feet in length should be removed and safely disposed. **For slopes over 35 percent in gradient, (the organic layer on the soil surface should be substantially disturbed or removed prior to fill placement or sidecasting.**

Figure 48. Hydraulic excavators are rapidly becoming the preferred equipment for wildland road construction. Here one is grubbing and clearing the alignment for a new forest road.

Cull logs and coarse slash can be piled in a row ("windrow") parallel to the road at the base of the proposed fill. When performed ahead of road construction, this practice can effectively control sediment movement from sidecasting and provide an economical, environmentally sound way of roadway slash disposal. This is especially useful when the road is being built near a stream channel. The height, width and length of these slash piles should be limited to allow for wildlife migration through the road corridor.

If an excavator is used to perform clearing and grubbing work, merchantable logs can be placed on top of windrowed slash piles for collection and loading when the road is passable to yarding equipment and log trucks. This practice reduces yarding costs. If some of the accumulated slash is to be burned, state fire regulations must be followed and permits obtained from the California Department of Forestry and Fire Protection and/or your local fire department.

D. Grading and compaction

Most forest and ranch roads are built by excavating a road bed out of naturally sloping ground. Thus, grading is when the bulk of soil excavation and disturbance occurs. **For a given road width, the steeper the ground the greater will be the volume of soil that is excavated or displaced during road construction** (Table 13). Road design and layout (flagging and stakes on the ground, together with plans and maps to look at) show equipment operators the correct alignment and the proper cutslopes and cutslope steepness to be developed along the new road. Operators may be asked to either construct roads using sidecasting methods on gentle terrain, to use cut-and-fill (with true compaction) on moderate slopes, or to employ full bench construction techniques on steep slopes or where the road is near stream channels.

1. Sidecast construction

In sidecast construction, the bulldozer starts at the top of the proposed cutslope, excavating and sidecasting material until the desired road grade and width is obtained. Material is pushed or "drifted" in front of the blade to areas where fill is needed (Figure 49). Road fill is used to cover culverts, and build up flat or low areas along the alignment. Since fill must support traffic, it needs to be spread and compacted as much as is possible to develop sufficient strength. Unfortunately, this common method of sidecast or "top-down" road construction does not lend itself to standard, engineered compaction methods where fill is placed and compacted in thin layers.

Figure 49. *Road constructed by cutting and sidecasting. A row of slash and organic debris along the base of the sidecast slope can help catch and filter soil eroded from the loose slope. Soil should only be sidecast onto* ***gentle or*** *moderate slopes that have been cleared and grubbed of vegetation, and where material cannot be eroded and delivered to a* ***stream.***

In sidecast construction, much of the spoil material moves down the slope below the final road bed and cannot be adequately compacted or contained. For this reason, **sidecasting construction methods are not suitable on steep or moderate slopes near stream channels where loose material could saturate during wet weather and slide further downslope. During sidecast construction, it is critical to avoid letting sidecast or waste material enter streams or placing it where it could erode and be delivered to a watercourse.**

Road construction can increase landslide risk by:
Oversteepening the slope with sidecast material
Overloading slopes by adding sidecast and fill material
Altering hillslope drainage by blocking or redirecting surface or subsurface water movement onto fillslopes or unstable soils
Removing material or undercutting the toe of a steep or potentially unstable slope

A general rule-of-thumb for moderately and steeply sloping lands is to keep sidecast everywhere less than about three feet deep, measured perpendicular to the original ground surface. Within about 400 feet of a watercourse, the sidecast should feather out within 30 feet of the road edge. This will minimize the risk of shallow landsliding, and of slope failures delivering sediment to stream channels. Roads built within a WLPZ, or roads constructed across moderate or steep slopes that extend, without significantly flattening, all the way downslope to a stream channel, should not have sidecast more than about 1 foot thick and it should feather out within about 10 feet of the road.

Overloading and oversteepening already steep or wet slopes with sidecast material during road construction is the single largest cause of road-related landslides. Sidecast failures are usually associated with ground slopes of 65% or steeper, although springs and seeps can cause failures at much gentler slope angles. To avoid surface ravelling and severe filling on sliver fills, 55-60% is the maximum ground slopes for stable sidecasting. A good rule-of-thumb is to not side cast on ground slopes of over 55%, and to not develop sidecast slopes exceeding about 65%. Road-related failures on lesser slopes occur mainly where breakdowns in the road drainage system redirect water onto the fillslopes.

A relatively new, more protective method of "sidecast construction" is gaining popularity with many road builders. This method utilizes a hydraulic excavator, instead of a bulldozer, to pioneer the road bench. The excavator is able to cleanly remove slash, stumps and logs and place them at *the*. base of the fillslope so they are not incorporated in the fill (Figure 50). It then grubs or cleans off the organic layer, excavates mineral soil and places it, bucket by bucket, beginning at the base of the slope (Figure 51). The powerful hydraulic system of large excavators permits them to partially compact the fill as it is placed. Spoil carefully placed using this method is more stable and less susceptible to failure than pushed or sidecast material. A fill face of about 65% is generally the steepest angle material can be placed at unless the fill is "engineered" using standard compaction methods, as described below.

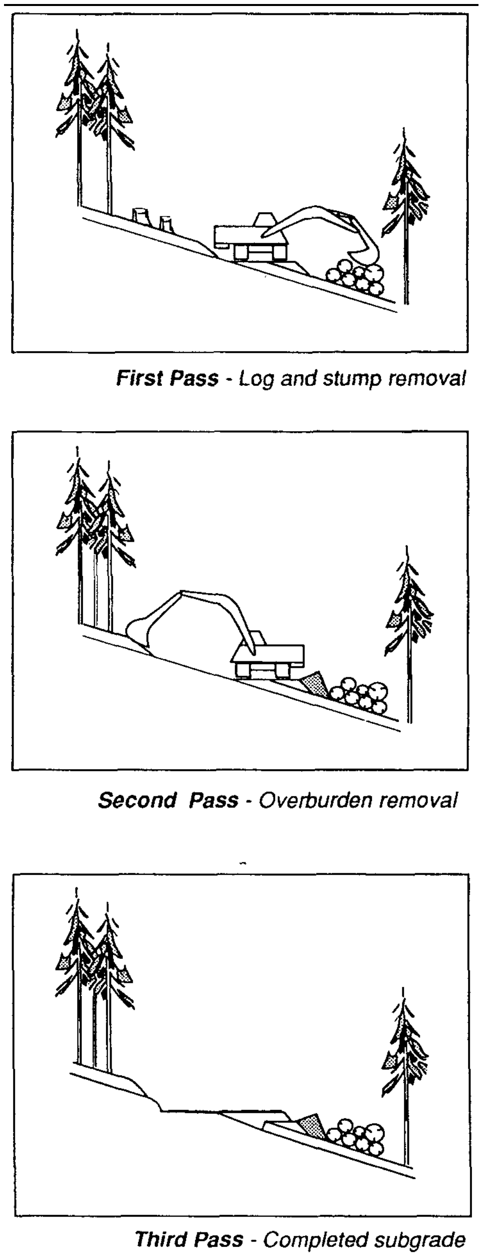


Figure 50. Excavators can perform a simple three step process of clearing and grubbing, excavating and subgrade development during construction of a balanced bench road. Using an excavator minimizes the volume of sidecast material. In the first pass an excavator operating from a pioneered bench removes logs and stumps, grubs the slope and installs a filter windrow of slash material at the base of the proposed fillslope. The second task is for the excavator to remove the overburden and place and compact the fill downslope above the windrowed slash. Thirdly, the uncovered, unweathered material is used to construct the bearing surface of the road(B.C.M.F., 1991).

Figure 51. Each step of the way, the excavator clears vegetation and grubs the slope surface in front of it before it excavates and extends the road bench. Excavated soil from the new segment of road bench is placed and compacted on the grubbed slope below the new segment of road bench. Cleared vegetation placed along the base of the future fillslope helps contain erosion from the exposed fill.

Filter windrows of slash material are easily formed and placed at the base of the fill by the excavator to contain surface erosion following construction. The excavator or a bulldozer then follows up on the pioneered road bench (Figure 52) to develop the final road width and surface shape, using the uncovered, unweathered material to construct the bearing surface of the road (Figure 53), which can then be surfaced for all-weather use (Figure 54).

*Figure 52. Behind the excavator, a bulldozer is used to prepare the final subgrade, surface shape and width of the new **road.***

Figure 53. New road constructed by excavator and bulldozer. Logs harvested from the right-of-way have been placed on top of the filter windrows and will be hauled away later.

Figure 54. Rock surfaced, outsloped forest road constructed by hydraulic excavator. Note the absence of an outside road benn which would otherwise collect and concentrate surface rwwff on the road prism.

2. Compacted cut-and-fill and benching construction

A variety of road benching techniques may be employed on moderate and steep slopes to improve the road's stability. These include balanced benching (using the excavator), sliver fills, backcasting, multi-benching, and full benching with endhauling. These techniques each utilize construction methods that can lend added stability to the road prism, compared to sidecasting. Each is also suitable for a specific soil and slope type, and should not be used in other situations.

Backcasting and multi-benching construction employs a technique called "bottom-up compaction" which adds stability to fill material placed along the outside of the road prism. ***Multi-benching* is not often used, but it is a good way to develop a stable footing with a minimum of**

sidecasting. First, a bench is cut at the proposed base of the fill, about 30 feet below the elevation of the proposed road grade (its exact location depends on the slope of the hillside and the width of the final road). It may be necessary to excavate and endhaul material from this first cut so that it is not sidecast downslope. Next, the operator moves slightly upslope to create another bench, casting the spoil material onto the first bench downslope where it is then compacted. After the second bench is completed, the process is repeated upslope to the final road elevation. The result is a fill that is keyed into the hillslope on multiple, small benches, with little sidecast (Figure 55).

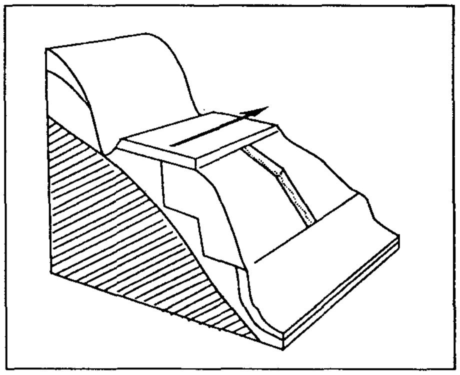


Figure *55. Multi-bench road construction.*

Single benching **is a more popular technique employing the same basic methods** as multi-**benching.** After the first (lowest) bench is cut, a bulldozer or an excavator may be used to cut into the hillslope above the bench to widen and raise the road bed. As cutting progresses in the upslope direction, the road bed is widened and layers of spoil material are added to the bench in thin "lifts" that are compacted as they are laid down. Cutting, filling and compaction of the road bed continues until the road reaches the final design grade and width (Figure 56).

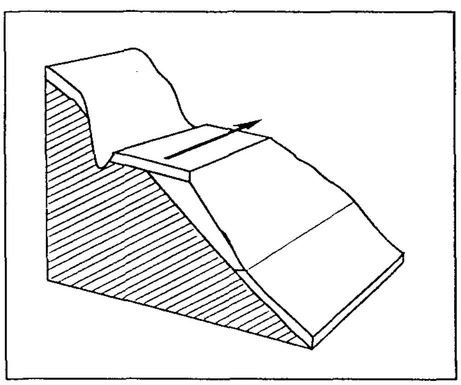
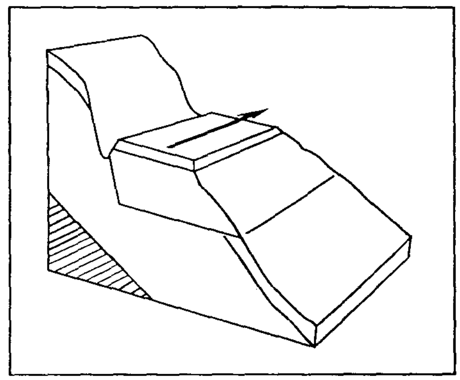


Figure 56. Single or "balanced bench" road construction, where the volume of cut material is balanced (equals) the volume of fill material that is placed nn the outside of the road bench. In most instances, a bench is excavated at the base of the proposed fill slope and layers of fill are placed in lifts and. compacted until the desired road level has been attained.

Remember, bulldozers and loaders are ***not*** efficient compactors. In critical situations where fill compaction is necessary to ensure that the material will not fail, true compactors should be used. Check with an engineer to select the correct equipment for the job. Compactors include grid, sheeps-foot, pneumatic, vibratory and tamping foot machines. Grid and vibratory compactors are appropriate for materials coarser than coarse silts and sands, while the others are preferred for sand and finer sized soil particles. Ask for advice.

Backcasting is a **method of producing a full bench road with no** endhauling. The soil must be medium to coarse grained and well drained, and the slopes cannot exceed 80%. It may not be a suitable technique on approaches to incised stream channels where emerging groundwater is commonly found. The surface immediately in front of the excavator is cleared and grubbed, and organic debris is either sidecast or windrowed at the base of the proposed fillslope. Then, a deep full bench is cut in front of the excavator about 25 to 30 feet wide and 8 to 10 feet deep at the road center line (again, depending on the slope of the land and the width of the road). The earth materials excavated from this cut are "backcast" and piled on the subgrade behind the excavator. Once the bench has been constructed, the piled subgrade material is leveled and graded by a bulldozer or the excavator, with little or no sidecasting (Figure 57). Because the roadbed materials are all excavated and placed, with little compaction, they should be allowed to settle and drain before the surface is outsloped or final ditches and ditch relief culverts are installed. On steep slopes, the fill will have to be reinforced or retained, and subdrains will be needed for springs and wet areas.

Figure 57. Backcasted bench road construction.

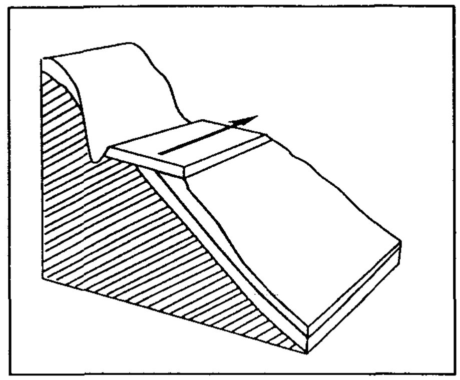


Sliverfill construction is a potentially hazardous method that can result in slope failures and water quality problems if material and site conditions are not correct. Sliverfills are thin fills lying parallel to the underlying hillslope, rather than as wedges used in normal cut and fill. Sliverfills cannot be compacted on slopes exceeding about 35%. On gentler slopes, sliverfills are small and relatively stable. As slopes increase, the fills become thicker and more susceptible to failure.

Sliverfill construction should be used only in special situations where 3/4 to full bench roads are constructed through rock or coarse alluvium and there is nowhere to dispose of the excess material. The rationale is to avoid producing an oversteepened slope by placing or spreading a thin veneer of coarse material on the ground surface at a slope less than its angle of repose (Figure 58). An excavator with a normal 35-foot reach can usually control and drape a sliver fill up to 40 feet downslope from the road bench.

Sliverfill construction should be a method of last resort, because the potential for failure is high, and a large amount of forest slope is taken out of production. Ravelling from the fill can also create a dangerous condition if there are roads or buildings downslope from the sliverfill. **Sands, silts and clays are completely unsuited for sliverfill construction. Sliverfills are not constructed by sidecasting, because uncontrolled sidecasting on steep slopes produces highly unstable deposits that ravel and/or fail by debris sliding.**

Figure 58. *Sliver fill road construction, in which a thin veneer of fill is "placed" (not sidecast!) over the slope below the road. Sliver fills should only be used in specific situations, usually with free draining broken rock materials where slope gradients are below the material's angle of repose, and there is no other place to put the material. Silts, clays and other fine grained soils are completely unsuitable for sliver fill construction.*

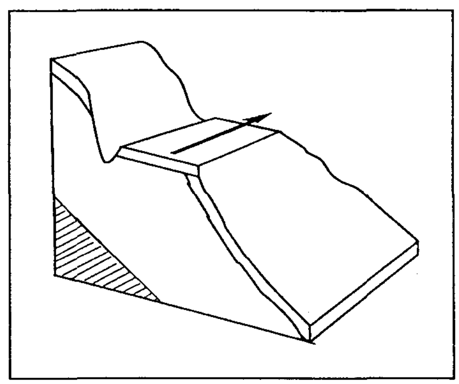


3. Full bench construction

Full bench **construction, the final method described here, typically involves excavation of the road bed using a hydraulic excavator.** A bench is cut into the rock or soil equal to the width of the road. No material is sidecast and spoil is used to fill low areas or stream crossings along the road alignment. Excess material can be hauled off-site to a stable storage location, while only a very minor amount can be safely drifted or feathered over and compacted on the road bench (Figure 59).

Full bench road construction is typically reserved for moderate or steep slopes, or where a road approaches or parallels a stream channel that could be impacted by sidecasting. Endhauling can be expensive, and full bench construction can cost four to seven times more than cut and fill methods. However, full benching without endhauling on steep slopes is a sure recipe for sidecast failure on many sites, as well as resultant impacts to downslope stream channels.

Figure 59. *Full bench road construction, in which all excavated material has been truck-endhauledfrom the site and deposited in a stable storage site.*



Full bench roads often result in tall cuts. Several rock and soil types may not support these large cutslopes. Unstable rock, including soft or highly fractured sedimentary rocks, or rocks with layering dipping steeply into the road cut, may not be suitable for full-bench cuts. These deep cuts can remove critical toe support and initiate upslope failure. Deep, soft clays, lake deposits and other earth materials with similar physical properties may also be unsuitable for tall cuts because of their susceptibility to rotational failure. Although balanced benching or backcasting may be better construction techniques for such soft and unstable soil and rock materials, it still may not be possible to build the road where slopes are steep and the rock is weak.

Excess spoil should be endhauled and stored at a stable location where it will not erode or fail and enter a watercourse. In addition, spoil should not be placed on unstable slopes, where the added weight could trigger land movement Excessive loading of clay or silt soils at an endhaul dump site could also cause a bearing capacity failure in the subsoil. Rock pits, wide, stable sections of road, ridges, benches and the inside edges of landings are typical locations where fill can be stored. All proposed fill sites should be field examined before construction. Those with emerging ground water or thick organic layers could experience slope failure after loading and should not be used.

For most situations, endhaul material is directly loaded into dump trucks by the excavator and hauled to the storage site where it is spread in layers that can be reworked by a bulldozer. In some cases, bulldozers can economically cany (push) spoil material to stable storage sites for distances up to 500 feet. The resulting spoil pile at the storage site should generally conform to the local topography to provide for natural drainage, and should be mulched and planted to control erosion (Figure 60).

Figure 60. *Typical spoil disposal site (uphill side of road) for endhauled spoil materials from a full bench road construction site. Spoil disposal site is located on a broad, gently sloping, dry ridge. Material is dumped, spread, compacted (by bulldozer) and seeded, mulched and planted.*

E. Constructing on wet soils

The application of coarse rock surfacing is a time-tested method for solving wet road surface conditions on forest and ranch roads. Rocking allows trucking and hauling on many roads during periods of wet weather. From 6 inches to over 18 inches of clean, graded rock may be needed to provide a stable, wet weather surface. While surfacing can double the cost of a road (Table 22), the rock or gravel cover provides a stable surface that can be used to extend the operating season without damaging water quality. However, if water is reaching the road bed from subsurface flow beneath the road fill (rather than from rainfall), measures in addition to surface rocking will likely be required to maintain surface stability and control erosion.

Table 22. Estimated cost distribution for constructing a typical forest road[1]	
Construction phase	**Average cost (%)**
Equipment and material	10%
Clearing, grubbing, slash disposal	20-25%
Excavation	20-25%
Culverts	10%
Rock surfacing	30-40%

[1] *USDA-SCS (1981)*

If small springs and seeps cannot be avoided when laying out the road alignment, special construction materials and techniques can be used to minimize wet soil problems. Established techniques for constructing clean gravel drains and surface rocking have been dramatically improved by the use of new, synthetic geotextile materials. These fabrics and engineering materials often come with detailed manufacturer's instructions that should be followed to achieve best results. Many companies provide free consultations to help in specific user applications.

Water emerging from road cutbanks can be controlled using a French drain or vertical drainage trench. The trench is excavated, lined on both sides and the bottom with a geotextile fabric, back filled with open graded, clean gravel and topped with fabric and soil. The fabric keeps fine soil materials from entering the trench and plugging the drain. The trench is then drained across the road prism in an outflow trench or subsurface drainage pipe situated down the ditch line.

Water emerging beneath the road bed can be controlled by installing a drainage blanket beneath the fill. This provides an easy path for the emerging water to flow out from under the road without saturating the road bed and overlying fill materials, thereby preventing rutting, rilling, muddy surface conditions or fill failures. In the field, a permeable geotextile blanket is laid down over the wet zone prior to road construction, and a gravel layer is backfilled over the top. This gravel blanket should slope to the outside edge of the road and "daylight" near the base of the fill to ensure proper drainage. Another geotextile layer is then laid on top and native soils are spread and compacted over the top until the desired road bed level is attained.

The above examples provide a brief introduction to the inexpensive and highly successful engineering methods now available to solve problems of subsurface drainage. Additional reading and research is highly recommended before using geotextiles for subdrainage. Assistance may be obtained from an experienced road engineer who has had success using these products, or from the field representative of a company that manufactures or distributes geotextiles designed for these applications.

F. Constructing on unstable slopes

The first rule of road construction is to stay away from unstable areas and landslides. However, there may be times when all other options have been exhausted and road construction in unstable zones is the least damaging alternative. **If road construction must occur on unstable slopes, it is highly recommended that an engineering geologist or geotechnical engineer be consulted to develop plans and construction methods for the specific road segment.** In situations where water quality would be seriously threatened by operations on unstable slopes, road construction or reconstruction projects may have to be deferred or entirely avoided. **Unstable slopes that threaten water quality must be recognized and considered *unsuitable* for road building.**

Some preventative measures can be applied to compensate for expected decreases in slope stability that often accompany road building. These include: 1) don't oversteepen or overload the slope with sidecast material, 2) don't alter the hillslope drainage by blocking or redirecting surface or subsurface flow onto the slide mass or by ponding water, and 3) don't remove material from the toe of the unstable slope or slide. These preventative measures should be applied when operating on slopes steeper than 50% to 55%, and may be necessary on some soil types at lesser gradients.

Most road-related failures are the direct result of excessive fill and sidecast on steep slopes, or concentration of runoff on road fillslopes. Narrow roads can significantly reduce the amount of material that must be excavated during road construction in these areas (Table 13). Thus, on steep slopes (over about 60%), sidecasting should be avoided. In addition, unstable soil types or the presence of springs and seeps may limit the use of sidecasting on slopes as low as 45% to 50% in order to minimize the potential for sidecast or "fill" failures.

It is especially important to avoid sidecasting on steep slopes in headwater swales, where hillslopes converge into a narrow, steep channel. These locations are prime sites for generating debris slides which can move thousands of feet downslope, scouring steep channels and depositing large amounts of sediment and debris that severely impact fish-bearing streams and domestic water supplies. Professional judgements and recommendations are critical for the identification of debris flow hazard and can best be made by a trained geologist or engineering geologist.

Debris avalanches on steep slopes can also be triggered by ground motion from heavy blasting during road construction or quarry excavation, especially during wet conditions. This suggests that the potential for initiating a landslide in the vicinity of blasting can be reduced by conducting blasting in the dry summer period. On steep slopes, excess blast material should be endhauled and not allowed to accumulated on the hillslope below the road.

The overall risk of slope failure can also be reduced by reducing total road length, especially for roads built across steep slopes. For example, using long-line or helicopter yarding systems can reduce road construction on unstable hillslopes by up to 50%, or more. Steep road gradients and pitches can also be used to reduce road mileage, and may be more cost-effective than full bench, end-haul construction across unstable areas or steep slopes. Employing locally steep road grades and pitches can be used to get your road onto low-maintenance, stable ridge-top areas and benches within the watershed. However, steep sections of road will often require outsloping, better ditching, more surfacing, and improved surface drainage compared to low gradient roads.

Knowing the boundaries of an unstable area (slide mass) is essential in selecting the type and location of cut and fill construction to be used. Cuts and fills can be located across some landslides with little effect on their stability, or even a net increase slope stability. For example,, the toe of some existing or potential rotational slides can be loaded with weight, or the head can be unloaded, without decreasing slope stability (Figure 61). Thus, a full fill road (using endhauled material and little or no cutting) at the toe or a full bench road (with endhaul) at the head of tills type of slide will not reduce stability and may even improve conditions (Figure 62). However, in spite of employing state-of-the-art road building techniques, slide movement may still continue. As a general rule, landslides and unstable areas should not be crossed with roads.

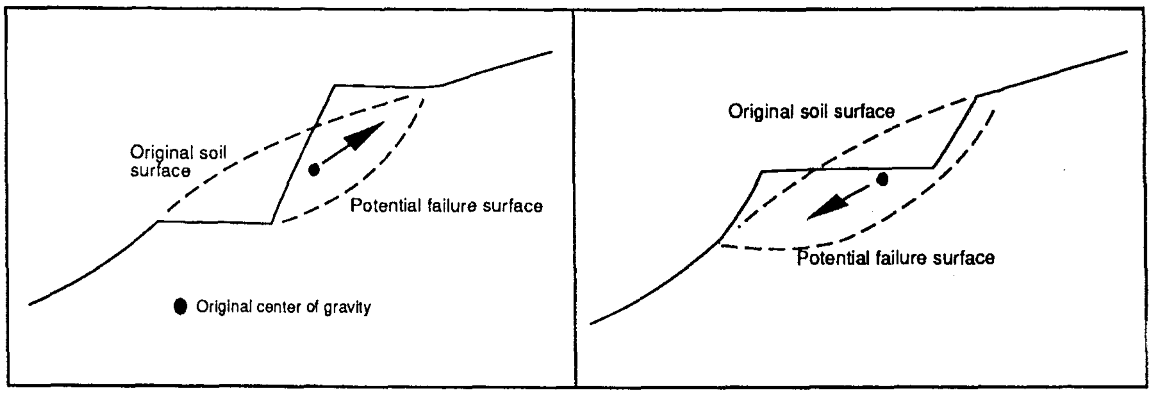


*Figure **61.** In general, the toe of a rotational slide should be loaded, whereas the head should be unloaded. Loading the head anal or unloading the toe (left diagram) acts to raise the center of gravity and actually decreases stability. Loading the toe anal or unloading the head shifts the center of gravity downward and can increase slope stability. This strategy does not work for other landslide types, where road building should be avoided.*

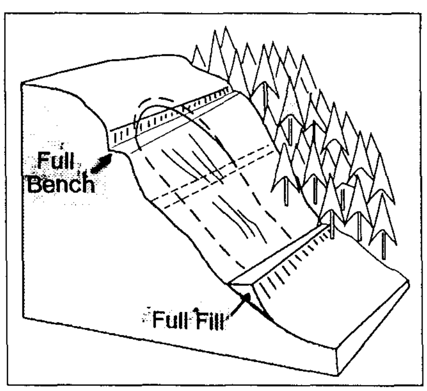


Figure 62. On certain rotational landslides, building a full fill across the toe (loading the toe), or cutting a full bench, endhauled road across the head (unloading the head} can be performed without decreasing slope stability. However, in most instances it is best to avoid unstable slopes altogether.

G. Constructing stream crossings

Common types of permanent stream crossings include bridges, culverted fills and fords as well as a variety of temporary stream crossings that are removed prior to the winter period. The use of "Humboldt" log crossings and unculverted fills are not suitable for permanent stream crossings, even through they were commonly used in past decades.

Constructing a stream crossing is a two part process consisting of: 1) constructing the road bench approaching and leaving **the** crossing site, and 2) constructing and installing the drainage structure and fill at the crossing.

1. Stream crossing approaches

Excavation of the approaching road is a critical part of constructing a stream crossing. If the channel side slopes are steep, any sidecasting on the approaches could easily deliver loose soil directly to the watercourse (Figure 63).

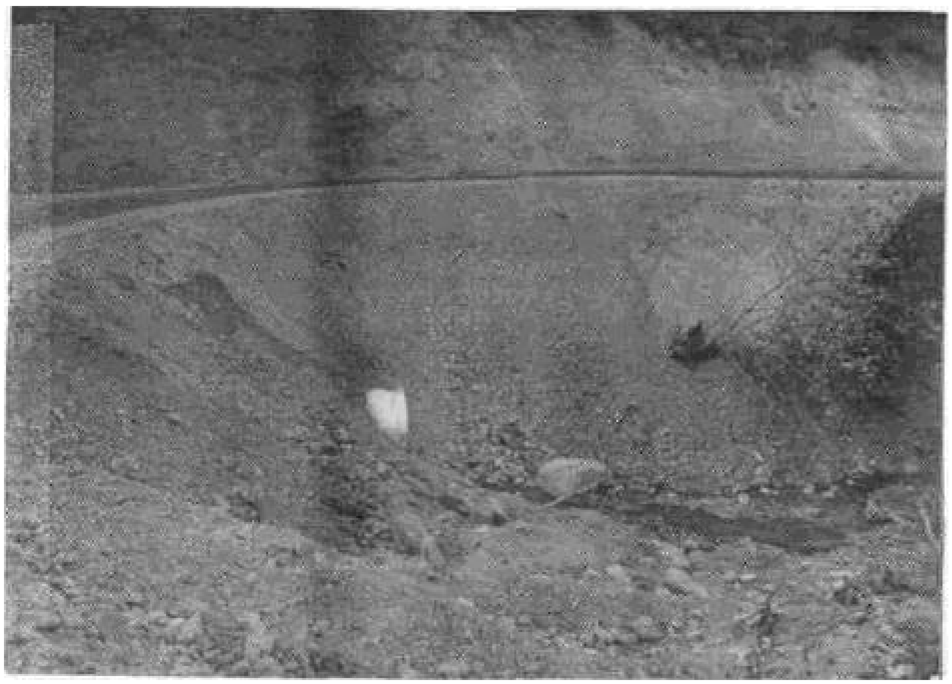


Figure 63. *Uncontrolled sidecasting on the approach to this stream crossing has delivered sediment directly to the stream channel. This type of road building is in violation of water quality standards and forest practice regulations.*

Where roads are to cross stream canyons or incised channels with steep sideslopes, the approaches to the channel should be built with full bench construction methods. Material may be endhauled with trucks or placed on the excavated road prism behind the excavator and pushed farther back from the crossing using bulldozers. ***Sidecasting should not be used!*** Excavators are ideal machines to perform full bench construction on difficult stream crossing approaches.

Roads which cross steep slopes in stream canyons also often pass through wet and/or unstable soil materials. Potentially unstable soils and slopes near a crossing site should be identified *before* the equipment cuts into *the* slope, so the approaches can be designed to avoid, or drain and stabilize, the unstable area. In wet areas, the road may need to be insloped and surfaced with rock to add stability and reduce erosion of the road bed.

Where roads are to cross channels with more moderate or gentle channel side slopes, full bench or cut-and-fill construction techniques can generally be used without damaging the stream. Roads can be pioneered using excavators to remove and place fill below and on the roadbed behind them without sediment reaching the stream channel. The excavated material can be stored temporarily for later use in the stream crossing fill, or a bulldozer can spread the material on the road bed away from the approach. Fill can also be placed in compacted layers at the base of the newly build road prism and used to construct a stable fill. **Regardless of the construction method chosen, sidecasting on stream crossing approaches should be avoided.**

2. Bridge installation

Bridges are usually the best, least damaging choice for stream crossing installations and should be considered for all larger, deeply incised or Class I (fish-bearing) watercourses. There is less disturbance during installation of bridges and there is less chance they will fail during floods. In recent years, the materials and installation costs for small precast or portable bridges have also become much more competitive with the installation of large culverts.

The main components of most bridges used for forest and ranch roads include bank abutments, stringers or steel cross-channel members, decking, running-planks and wheel guards. Most **of** these parts can be pre-assembled off-site and quickly installed at the crossing location, or the bridge can be constructed entirely on-location.

As with culverted stream crossings, the greatest potential impact to stream channels occurs during bridge installation. Above all, installation should minimize or eliminate the use of equipment in the stream. A low impact equipment crossing (ford) may be needed in the immediate vicinity of the crossing to prepare both abutments and approaches for placement of the bridge. If approved by the Department of Fish and Game, this ford may later be used by tracked equipment crossing the stream to avoid damaging the bridge decking (Figure 64). If the stream is too large or deeply incised to be crossed with heavy equipment, access will need to be developed from the other side. In either case, construction activities should result in only minimal disturbance to, and no sidecasting into, the watercourse channel.

__Figure 64.__ Many bridges built on small forest and ranch roads cannot support or would be damaged by heavy tracked equipment passing over them. For this reason, an adjacent equipment ford is sometimes constructed. These steep fords can erode and deliver sediment to the stream channel if they are not waterbarred, mulched and seeded prior to winter rains.

Successfully designing and installing a permanent or temporary bridge across a watercourse requires forethought and planning, and an experienced equipment operator and engineer may be required. First, the bridge abutments should be prepared and placed (or constructed) on each bank to accept the bridge. "Permanent" bridges may be secured to the banks by using piles driven at least 10 feet into the natural ground, or by using a cast or precast concrete abutment that is pinned and grouted to the bedrock or is cabled to deadmen buried behind the abutment Temporary bridges may also need to be set on or secured to abutments such as logs or precast concrete slabs (Figure 65).

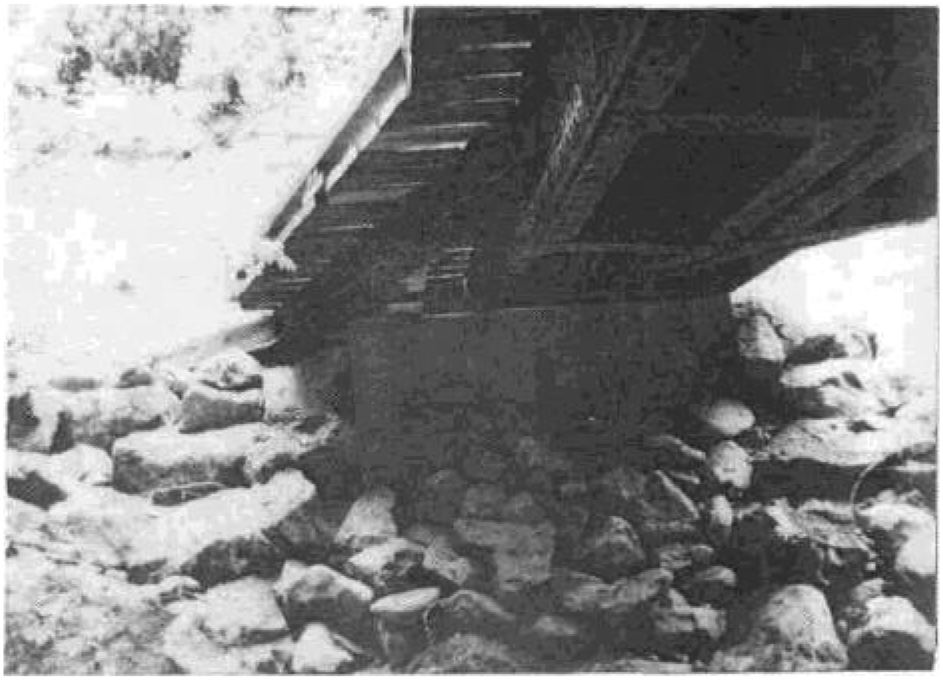


Figure 65. *Bridge abutments can be built of logs, piers, concrete pads and other supports. This abutment is a precast concrete support that was fabricated off-site and installed when road construction reached the crossing location. It is tied into the adjacent slope with cables secured to buried "deadmen."*

Each abutment should be leveled and secured far enough into the bank so that slumping or bank failure will not occur. Abutments and piers should be parallel to the stream channel and set back from the channel to prevent *any* narrowing of the streambed and banks. The bridge crossing should be at right angles to the channel, and, if possible, with at least 50 feet of straight approach before the bridge, but the bridge does not have to be level lengthwise across the stream (Figure 66).

Figure 66. *Railroad flatcar bridge correctly crosses stream channel at a 90° angle, but bare, unprotected soil abutments are subject to erosion during high flaws. Low, summer stream/low goes subsurface under the bridge because of extra sediment in the channel bottom at the crossing site.*

The grade of the bridge should be the same as the grade of the approaching road. To avoid draining road surfaces directly into the stream, bridges should not be located at the bottom of an abrupt dip in the road grade (Figure 67). If the road climbs away from the crossing in one or both directions, the approaches should be flattened for at least 50 feet, with road surface runoff directed into a ditch relief culvert or rolling dip which drains into a vegetated buffer strip before reaching the bridge site.

Figure 67a. *The segments of road which approach a bridge should not drain onto the bridge surface. Otherwise, soil eroded from the adjacent road surface can be carried onto the bridge and into the stream.*

Stringers and structural supports to be used for the bridge should not be dragged through the streambed. A crane, an excavator, or an excavator and a winch-tractor can be used to move a portable bridge into place, with one piece of equipment on each side. If decking is installed on the bridge surface, it should be laid and bolted solidly across the top to provide a good bearing surface and to spread the load of vehicles to all the spanning log stringers or structural steel members. On wood bridges, running planks can be attached to the decking. Bolts should be used to attach the decking because spikes tend to loosen and come out as the bridge flexes under heavy loads. Finally, for safety reasons, poles, sawn timbers or metal wheel guards should be installed along the outside edges of the bridge to alert drivers who wander off the running surface and too near the edge of the deck (Figure 68).

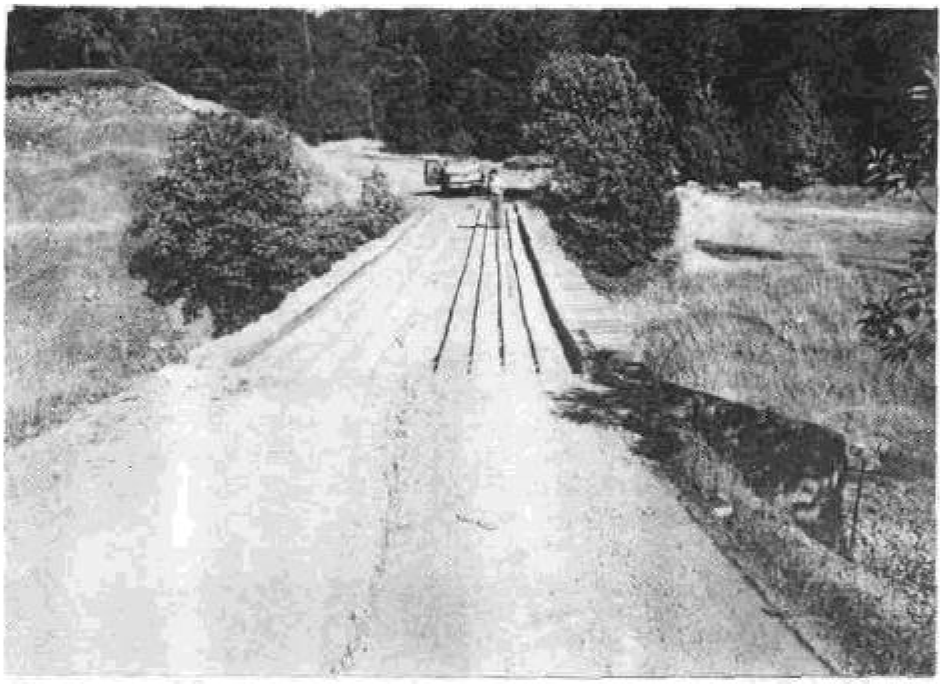


Figure 67b. *If the bridge is at a low point in the road grade, make sure the uphill road surface is well drained before the bridge and consider surfacing the approaches with rock or paving. Preferably, the bridge approaches should be flat or slightly elevated (see Figure 68).*

Figure 68. *Wheel guards on a railroad flatcar bridge signal the driver that he is too close to the edge of the bridge. Note how the approaching road slopes up to the bridge so that road runoff does not flow onto the. bridge deck*

3. Culvert installation

During road building, the construction of culverted stream crossings has the greatest potential of all activities to cause immediate sediment pollution. Culverts should be properly aligned, bedded, backfilled and covered, or they will be subject to eventual failure. In all cases, disturbance to the stream banks and streambed should be minimized during stream crossing construction.

If the stream is flowing at the culvert installation site, the crossing can be dewatered by constructing a small diversion dam just upstream and pumping or diverting flow around the project area. The dewatered stream channel is then cleared for the culvert. Large rocks and woody debris should be removed. Both the culvert foundation and trench walls must be free of logs, stumps, limbs or rocks that could damage the pipe, or subsequently cause seepage of flow around the outside of the culvert.

The culvert should be aligned with the natural stream channel. Correct alignment is critical for the culvert to function properly. Misalignment can result in bank erosion and debris plugging problems. **Stream crossing culverts should also be placed at the base of the fill, and at the grade of the original streambed.** The culvert should be inset slightly into the natural streambed so that water drops several inches as it enters the pipe. Culvert inlets set too low can plug with debris and those set too high can allow water to undercut the culvert (Figure 69). Culverts placed midway up the outside of the fill are more likely to plug with sediment or organic debris, because their ability to pass materials is reduced, or to cause erosion of the fill below the culvert outlet

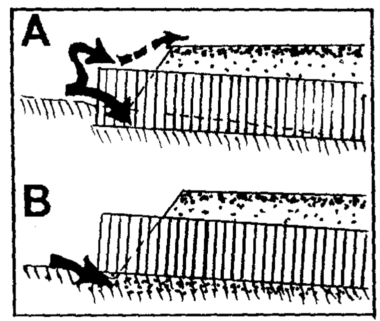


Figure 69a, b. *Proper culvert installation involves correct culvert orientation, setting the pipe slightly below the bed of the original stream, and backfllling and compacting the fill as it is placed over the culvert. Installing the inlet too low in the streambed (A) can lead to culvert plugging, yet if it set too high (B) flow can undercut the inlet (fromM.D.SL.,1991).*

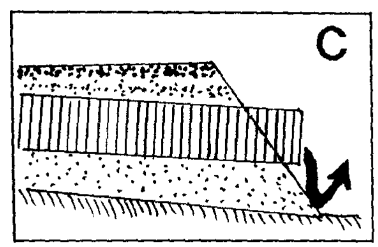


Figure 69c. *If the culvert outlet is placed too high in the fill (C), flow at the outfall will erode the fill.*

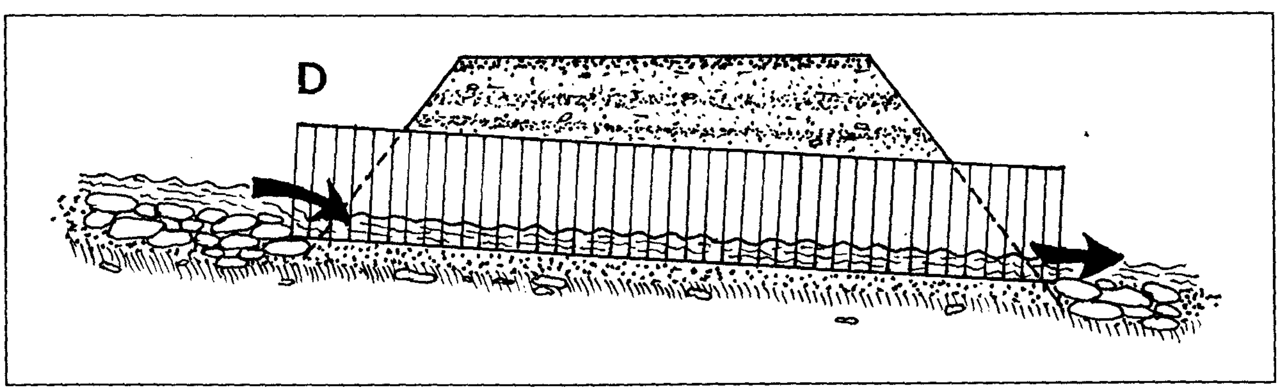


Figure 69d. *Placed correctly (D), the culvert is set slightly below the original stream, grade and protected with armor at the inlet and outlet.*

The culvert bed may be composed of either compacted rock-free soil, or gravel (Figure 69e). If gravel is used for the bed, filter fabric will be needed to separate the gravel from the soil to minimize the potential for soil piping. Bedding beneath the culvert should provide for even distribution of the load over the length of the pipe. Nearly every culvert will sag after it is buried. To allow for this, all culverts should be installed with a "camber" or slight hump in the bed centered under the middle of the pipe. The amount of camber should be between 1.5 to 3 inches per 10 feet of culvert pipe lengA. Natural settling and compaction which occurs after backfilling will then allow the pipe to settle into a straight profile.

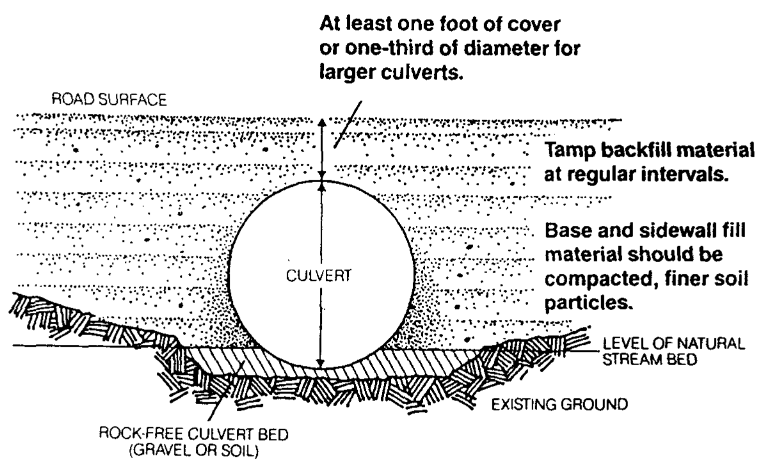


Figure 69e. *Rock-free fill is backfilled over the culvert in layers and compacted under the pipe and around the sidewall (E).*

Backfilling can begin once the culvert is in-place in its bed. Backfill material should be free of rocks, limbs or other debris that could dent the pipe or allow water to seep around the pipe. One end of the culvert should be covered, and then the other end. Once the ends are secured, the center is covered. Careful pouring or sifting of backfill material over the top of the pipe using a backhoe or excavator bucket will allow finer particles to flow around and under the culvert sides. Larger particles will roll to the outside. The fine soil particles will compact more easily and provide a good seal against leaks along the length of the pipe.

The backfill material should be tamped and compacted throughout the entire installation process. The base and sidewall material should be compacted before the pipe is placed in its bed. A minimum amount of fill material should be used for the bed of the culvert to reduce seepage into and along the fill. Backfill material should then be compacted at regular intervals (in approximately 0.5-1 foot lifts) until at least 1/3 of the diameter of the culvert has been covered (Figure 69). This will prevent leaking. A vibrating, gas-powered hand-compactor can be used.

Once backfilling has been completed, the inlet and outlet of the culvert should be armored. A metal, concrete, sandbag or rock head-wall can be constructed to prevent inlet erosion (Figure 70). A trash protector can be installed just upstream from the inlet where there is a hazard of floating limbs and wood chunks plugging the culvert inlet. This is especially important on logging roads where the upslope areas have recently been harvested or are slated for harvesting in the future.

If the stream is live, flow through the culvert should be observed to determine if and where additional rock armor is needed. As a precaution against sedimentation in the stream, a slash windrow can be constructed at the base of the road fill around and adjacent to the culvert outlet so that soil is not sidecast into the stream channel or onto the inlet during final grading of the road bed. Mulching and grass seeding can also be used on the bare fillslope to reduce erosion.

***Figure** 70. Culvert installation on a low gradient Class II (non-fish bearing) watercourse. Culvert is set slightly into the original streambed and inlet is armored to prevent erosion. Roadbed dips into and out of the stream crossing and trash rack (not visible) has been installed just upstream from the culvert inlet.*

Final filling of the stream crossing can now be performed. Layers of fill are pushed over the crossing until the final, design road grade is achieved. Fill should be placed over the top of the culvert to a depth of at least 1 foot, for 18" to 36" culverts, or a minimum of 1/3 to 1/2 the culvert diameter for larger pipes. If adequate cover cannot be achieved, then a pipe-arch or two smaller culverts should be installed (Figure 71).

***Figure 71. Pipe arch** culvert installed in a Class I fish bearing watercourse. Fill face has been **rock** armored to prevent erosion during high flows. Because of the shallow fill, a second pipe arch culvert was installed to upgrade the crossing to pass the 50-year flood flow.*

It is common practice to inslope the road bench at stream crossings, so that road surface runoff flows inward to the culvert inlet, rather than over the newly constructed, unprotected face along the outside of the fill. To minimize road runoff directly entering the crossing, the approaching road can be outsloped or a rolling dip can be placed just up-road from the crossing to drain the road surface. In addition, a dip should be placed in the road at the down-road edge of the fill to provide for a "fail-safe" drainage design (see Chapter V). If the culvert plugs, the stream will then flow over the road bench and back into the channel, not down the adjacent road bed.

Alternatively, you can construct the road with an outslope through the crossing. Road surface runoff can be controlled with an outside berm and then discharged onto native ground at the down-road edge of the fill, or carried to the base of the new fill in a berm-drain or open top culvert, or across an armored (rock surfaced) drain. Berms, however, are prone to failure and should only be used where regular, wet season maintenance is available. If the fill face is heavily vegetated with grass by the time of the first fall rains, the berm may not be necessary to prevent surface erosion.

Installation of ditch relief culverts follows the same basic principles as culverts for streams. They should be installed at a 30 degree angle to the ditch to lessen the chance for inlet erosion and plugging. Ditch relief culverts should be installed at a slope of 2-4 percent more than the ditch grade, or at least 5 inches every 10 feet (Figure 33). This will ensure sufficient water velocities to carry sediment through the pipe.

Ditch relief culverts should be seated on the natural slope. The bedding and fill material should be free of rocks and debris that could puncture the pipe. Backfill materials should be compacted from the bed to a depth of 1 foot or 1/3 the culvert diameter, whichever is greater, over the top of the culvert. The culvert outlet should extend beyond the base of the road fill (or a flume downspout is used) and empty onto an apron of rock, gravel, brush or logs (Figure 72).

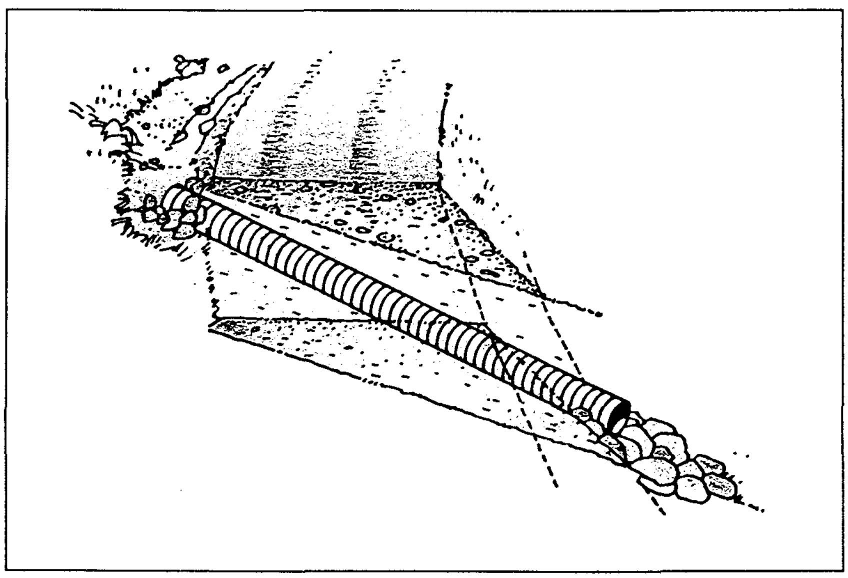


***Figure** 72. Like stream crossing culverts, ditch relief culverts should be installed at the base of the road fill, with armoring at the inlet and some type of energy dissipation at the outfall. If the culvert is placed higher in the fill, a downspout should be used to carry flaw from the outlet downslope past the base of the fill (M.DSL.,1991).*

4. Temporary stream crossings

By definition, temporary stream crossings are designed to be removed. As with bridges, installation of a temporary crossing should be done with the minimum possible amount of disturbance to the channel bed and banks, and using the least amount of fill material possible. The goal is to leave the site in a relatively undisturbed condition that is subject to minimal erosion following removal of the crossing.

As with the installation of all other stream crossings, there should be little or no sidecasting on the approaches to the channel. Colorful flagging, straw mulch or some other marker should be spread over the channel bottom so it is possible to identify the bottom of the natural channel when the temporary crossing is removed. The temporary crossing is then constructed on top of this marker.

For poorly incised, dry channels, rock-lined dry-fords can be installed as long as they are completely "pulled" or removed at the completion of use, or before the beginning of the winter period (whichever occurs first). Dry fords work well where the approaches to the channel are relatively flat. The road is built to dip across the channel using as little fill as is possible, and any fill along the outside edge of the road can be armored with fabric and appropriately sized rip-rap, or with an over-side drain. If the watercourse is incised and/or is flowing at the time of installation, temporary log, log-and-culvert, culverted fill or temporary bridge crossings can be installed'.

For log crossings, vegetation is first pruned from along the alignment and from the streambed and banks, as opposed to being stripped or bladed with a tractor. Next, straw is placed on the bed and against the banks, to help identify the original channel margins and to protect the channel from disturbance. In a flowing stream channel, a culvert capable of carrying flows expected during the period of operation should be placed at the base of the log fill. Logs are bundled into groups using choker cables and then lowered into the channel. Cabled logs make removal a simple, one-step operation using a bulldozer, loader or excavator. When the log "fill" has been built up to within about 18 inches of the temporary crossing grade, the remaining large spaces can be filled with smaller logs. A 6-inch layer of straw is then placed on top of the logs to prevent the overlying road surface soil from infiltrating through the logs to the streambed and being washed downstream[2] (Figure 73). Local soil is generally adequate for the running surface, and the straw layer enables easy removal of the capping soil fill.

1 The most common type of temporary bridge crossing used on forest and ranch roads is the railroad flatcar bridge. See the previous section on **bridge installation** for guidance on installing temporary bridge crossings.

2 Filter fabric can be used with or instead of straw on top of the logs, to keep sediment from filtering down into the stream, but it is difficult to clean out when the crossing is removed. Sediment is often spilled into the stream channel during crossing removal. Straw alone usually works better.

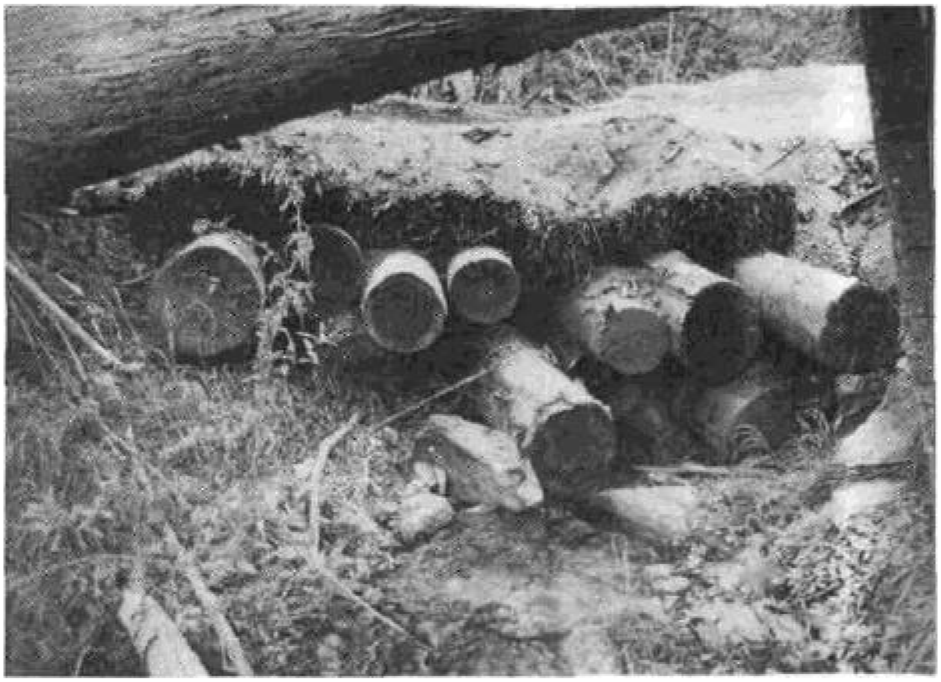


Figure 73. End view of a temporary stream crossing. First, a culvert was placed in the channel bottom. Then cabled logs were placed on top, followed by a thick layer of straw and then soil material for the temporary running surface. The materials comprising the temporary crossing are easily removed upon the completion of operations.

H. Rolling dips

Rolling dips are simply breaks in the grade of a road. They are sloped either into the ditch or to the outside of the road edge to drain and disperse road surface runoff. Rolling dips are installed in the road bed as needed to drain the road surface and prevent rilling and surface erosion (Tables 3 and 17), and are most frequently used on outsloped roads. As a road becomes steeper, rolling dips should be made deeper and placed at a steeper angle to adequately capture and divert road runoff (Figure 74).

Figure 74. Several rolling dips in close succession on a rocked, outsloped road built across moderately steep terrain. As road grade increases, rolling dips need to be spaced more closely.

It is easier to properly locate and construct rolling dips when they are designed into the original road plan. However, they may also be installed on existing roads to improve surface drainage where they can be built in about one hour, or less, using a medium size bulldozer (D-7 size). Unsurfaced roads are more easily reconstructed with rolling dips, but rocked road surfaces can also be reconfigured.

Excavation for a rolling dip typically begins 50 to 100 feet up-road from where the axis of the dip is planned (Table 18). Material is progressively excavated from the road bed, slightly steepening the grade, until the axis is reached. This is the deepest pan of the excavation, with the overall depth being determined by the slope of the road. The steeper the road, the deeper the dip will have to be in order to reverse grade (Table 18).

In order to safely and effectively direct runoff to the side of the road, the axis of a rolling dip should be angled about 30 degrees to the road alignment. On the down-road side of the rolling dip axis, the road bed slope should actually rise slightly to ensure that runoff cannot continue down the road surface. This is called a "grade change" (Figure 28). The rise in grade is carried for about 10 to 20 feet before the road surface begins to fall again at its original slope. This transition from axis bottom, through rising grade, to original falling grade is achieved in a road-distance of 15 to 30 feet. **Unlike a waterbar, the reverse grade portion of a rolling dip is not composed of fill. The entire drainage structure is excavated into the roadbed.**

Rolling dips require very little maintenance if they are constructed properly and at an adequate spacing. They should not collect enough runoff to develop significant erosion. The length and depth of the rolling dip should be adequate to divert road runoff but not so great as to interrupt or endanger traffic at normal speeds. Care should be taken to ensure that grader operators do not fill the depressions with soil or cut deeply into the lower part of the rising section, thereby eliminating the change-in-grade.

I. Subgrade and surfacing

The road surface can be a big source of stream sediment In some watersheds, it may be the primary source of accelerated (man-caused) erosion and sediment yield from the road system. Proper road construction and surfacing can significantly reduce this source of fine sediment.

Permanent roads that are to be used for winter and wet weather hauling, including ranch roads and roads used for commercial hauling of forest products, need to be surfaced to improve trafficability and reduce erosion. Roads which receive heavy use should be inspected regularly to discover early signs of damage. Serious damage to road surfaces usually begins with the build up of thick (1-4 inch) accumulations of dry dust during the summer, or excess water (and mud) during the winter. Standing water is a sign of poor road drainage and ruts indicate that road strength is deteriorating.

A stable and well drained subgrade is essential for a good road. The load bearing capacity of a road depends upon the subgrade's soil strength, drainage and compaction characteristics (Table 23). Native material is often suitable, and can be used for the road's subgrade. Weak or wet subgrades (soils unable to support a load by themselves) need to be strengthened by adding loose or crushed rock or gravel to provide ballast and distribute the stress placed on the soil.

Table 23. Soil characteristics for road subgrade materials[1]				
Material type	**Strength, compaction and foundation suitability**	**Drainage**	**Reaction to frost**	**Common symbols of soil types[2]**
Clean gravels and clean sand[3]	Good to excellent	Excellent	None to slight	GW, GP, SW, SP
Gravels and sands with non-plastic[4] fines	Good to excellent	Fair to poor	Slight to high	GMd, SMd
Gravels and sands with plastic[4] fines	Fair to good	Poor to impervious	Slight to high	GMu, GC, SMu, SC
Non-plastic and slightly plastic[4] silts and clays	Poor to fan-	Fair to impervious (mostly poor)	Medium to high	ML, CL, OL
Medium and highly plastic[4] silts and clays	Very poor to poor	Pair to impervious (mostly poor)	Medium to very high	MH,CH
Peat and other highly organic soils	Very unstable, poor compaction	Fair to poor	Slight	Pt

[1] *W.D.NJR. (1982)*

[2] *Unified Soil Classification System (USCS) symbol*

[3] *"Clean" means less than about 12% of the material is smaller than 1/64" (the smallest particle visible to the naked eye)*

[4] *Plasticity can be tested by simple field methods, including lightly wetting a hand sample, rolling the fines into a ball and then into a thread before it crumbles:*

> ***Non-plastic:*** *a thread cannot be formed, regardless of the moisture content.* ***Low plasticity:*** *after 2-3 times, the molded ball will crumble.*
>
> ***Medium plasticity:*** *After 3-5 times, the ball will easily crumble with moderate force (pressed between thumb and forefinger.*
>
> ***High plasticity:*** *ball will not crumble, even with moderate force, after five times.*

Wet, low strength soils may be stabilized by the use of synthetic fabrics (geotextiles) designed specifically for this application. The fabric is spread over the subgrade and then covered with a layer of rock. Water passes through the membrane, but the wet soil remains below and does not mix with the surface aggregate. As a result, the road dries faster and the fabric spreads the wheel loading pressures over a large surface area.

The running surface of the road should be smooth and hard-wearing, and it should not be subject to blowing or washing away. The most commonly used surfacing materials are angular (crushed) rock. In the past, river-run gravel was frequently used where crushed rock was not readily available. However, rounded material is not as well suited as long lasting surfacing material and may be difficult to keep in-place.

First, a "base course" of 2 to 3 inch diameter angular rock is usually dumped on the compacted native road surface using dump trucks, spread to a uniform depth using a grader or tractor and then compacted. The use of true compaction equipment (instead of tractors) will provide the best, longest lasting road surface. Geotextile engineering fabrics can be used beneath the base course material if soil conditions are wet. A finer "surface course" several inches in thickness is then spread over the compacted base coarse material to provide a dense, smooth running surface. The resulting layers of angular, interlocking rock will provide a low impact road surface that can be used during much of the winter (Figure 75).

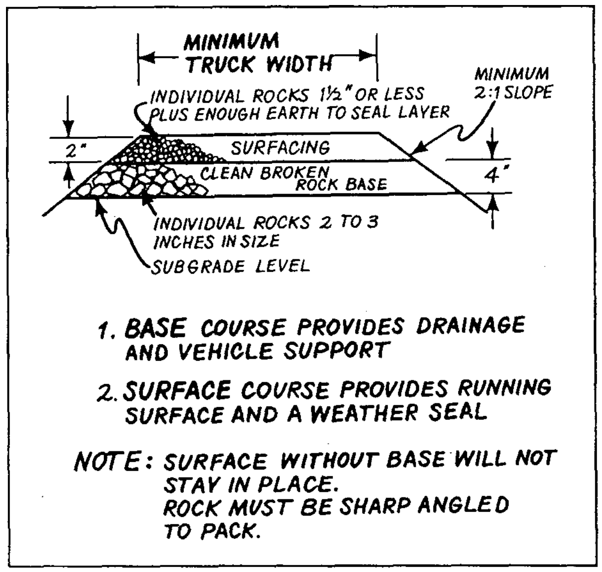


***Figure** 75. Cross section diagram showing typical base-course and surface-course application for forest and ranch roads (USDA-SCS, 1983).*

For all-weather use, angular rock should be placed to a total depth of 6-10 inches, or more, which will then compact to a finished depth of 4 to 6 inches under normal use. Table 24 lists the volume of aggregate needed to surface one mile of road, ranging from 10-20 feet wide, to a depth of 1-6 inches.

Table 24. Aggregate (yds^3) required to one mile of road[1]

Road width (ft)	Depth of uncompacted rock (inches)					
	2"	4"	6"	8"	10"	12"
10'	326	652	978	1,304	1,630	1,956
12'	391	782	1,174	1,564	1,956	2,348
14'	456	913	1,369	1,826	2,282	2,738
16'	522	1,043	1,565	2,086	2,608	3,130
18'	587	1,174	1,760	2,348	2,934	3,520
20'	652	1,304	1,956	2,608	3,260	3,912

[1] *USDA (1978). Uncompacted, 16.3 yds^3 equals I inch deep by I foot wide by 1 mile long. When aggregate is compacted, increase volumes required by 15-30%, depending on type and gradation of material.*

J. Erosion control during construction

Road construction, use and maintenance can cause soil erosion and stream sedimentation problems. In fact, roads have been identified as one of the greatest sources of man-caused erosion and sediment yield in forested watersheds of the Pacific Northwest. Some erosion is the result of poor road location and design, but some clearly comes from inadequate planning for erosion and sediment control on the construction site. Proper forest and ranch-land road construction and maintenance practices reduce long-term erosion and stream sedimentation from forest and ranch lands. However, even properly located, designed and constructed roads still need erosion control measures to minimize soil loss and sediment production.

1. Roads and landings

Both mechanical and vegetative measures are needed to minimize accelerated erosion from roads and landings under construction. Effective erosion prevention employs proper road location, pre-planning of cuts and fills, minimizing soil exposure, compacting fill or endhauling loose fill materials from steep slopes and stream-side areas, developing stable cut and fillslopes, mulching to control surface erosion for the first year, and seeding and planting to provide for longer-term erosion prevention.

Perhaps the best tool for preventing erosion is to keep soil disturbance to an absolute minimum during construction. Cuts and fills on gentle and moderate slopes should be balanced to minimize the amount of excavation and soil exposure. On steep slopes, or where soils are unstable, full bench construction techniques should utilize "bottom-up" compaction or endhauling to eliminate problems associated with loose, uncompacted fill materials and sidecasting. Soils that are wet and would become muddy should be allowed to dry before construction begins or continues.

Cut and fillslopes need to be constructed at stable angles to prevent mass failure. Slopes which develop instability, especially those which threaten to deliver sediment to stream channels, need to be stabilized immediately. Woody debris should not be incorporated in sidecast fill material during construction because it will decompose and can lead to future slope failure (landsliding). Woody debris and soil mixed together around the outside perimeter of landings built on steep slopes form a certain recipe for eventual landsliding.

Shallow failures or small slumps on the cutbank or fillslope can either be excavated (if they threaten to deliver sediment directly to the stream channel) or stabilized by placing large rocks at the slope base to buttress the unstable materials. Specific techniques for building rock buttresses, retaining walls, timber cribs, and reinforced slopes are beyond the scope of this manual and require advice and design by a qualified engineering geologist or geotechnical engineer.

Bare slopes created by construction operations also need to be protected until vegetation can stabilize the surface. Surface erosion on exposed cuts and fills can be minimized by mulching, seeding, planting, compacting, armoring and/or benching prior to the first fall rains. Installing filter windrows of slash at the base of the road fill can minimize the movement of eroded soil to downslope areas and stream channels. They are installed using heavy equipment as the road is being cleared and graded. During construction, it is also important to retain rooted trees and shrubs at the base of the fill as an "anchor" for the fill and filter windrows (Figure 76).

Figure 76. Newly constructed, outsloped forest road with accumulated line of slash, called a filter windrow, at the base of the fill to catch soil eroded from the fill slope. Slash should be placed at the base of the fill, and not Incorporated into the soil material. This fill has been straw mulched and is covered with a thick stand of grass. Filter windrows are most important to install where roads approach and cross stream channels. Note how the road conforms to the topography of the land and incorporates rolling dips at natural swales to shed surface runoff.

Road construction activities should be performed during the "dry" season, and all surface drainage structures should be in-place and completed well before winter rains are expected (October 15 for forestry-related roads). Where construction or reconstruction activities are conducted near a live watercourse, silt fences and/or straw bale silt-dams may be needed both in the channel and on the adjacent slopes during the construction phase. Any use of roads during the winter period may require the application of road surfacing to prevent road deterioration, control erosion, and prevent sediment transport to nearby streams. Muddy runoff from unsurfaced roads can transport large volumes of sediment that flows through culverts and into streams.

2. Spoil disposal sites, borrow sites and rock pits

Erosion should also be controlled in areas where large expanses of bare soil have been created, such as spoil disposal sites, borrow sites and rock pits. Proper location, excavation and topographic development of spoil disposal sites and rock pits are key elements to assuring controlled drainage and minimizing erosion and sediment problems. When placed on slopes; spoil should be spread in lifts and compacted to develop strength in the materials. Spoil disposal Mes, borrow sites and rock pits should not be located near streams or where sidecast, tailings or sediment-laden runoff could reach a watercourse.

When a rock pit is under development, top soil and overburden should be stockpiled for later use as surface soil for reclamation. During development and use of borrow pits and disposal sites, it is also important to maintain internal and controlled external drainage. Outflows should be dispersed to prevent erosion and water should be directed through vegetated filter areas to trap sediment Runoff should not be directed straight to a watercourse.

Filled spoil areas and exhausted rock pits should be permanently reclaimed. Development and reclamation of rock pits on private lands may be subject to regulations under the California's Surface Mining and Reclamation Act (SMARA) if the proposed excavations are greater than 1 acre in size or 1000 yds3 in volume (Figure 77). Spoil sites should be mulched and seeded, **or** machine hydroseeded using a mulch and seed slurry, before winter rains. Compacted areas should be ripped to promote revegetation. Areas of bare rock should be outsloped and covered with several feet of soil. Then, bare areas should be planted with brush and tree species that will be able to thrive in the altered environment.

***Figure** 77 a. Access road and rock pit before (A) and after (B) reclamation. Exposed areas have been reshaped and covered with soil to promote revegetation. The area was then mulched, seeded and planted. Reclamation work was performed using an excavator and large bulldozer.*

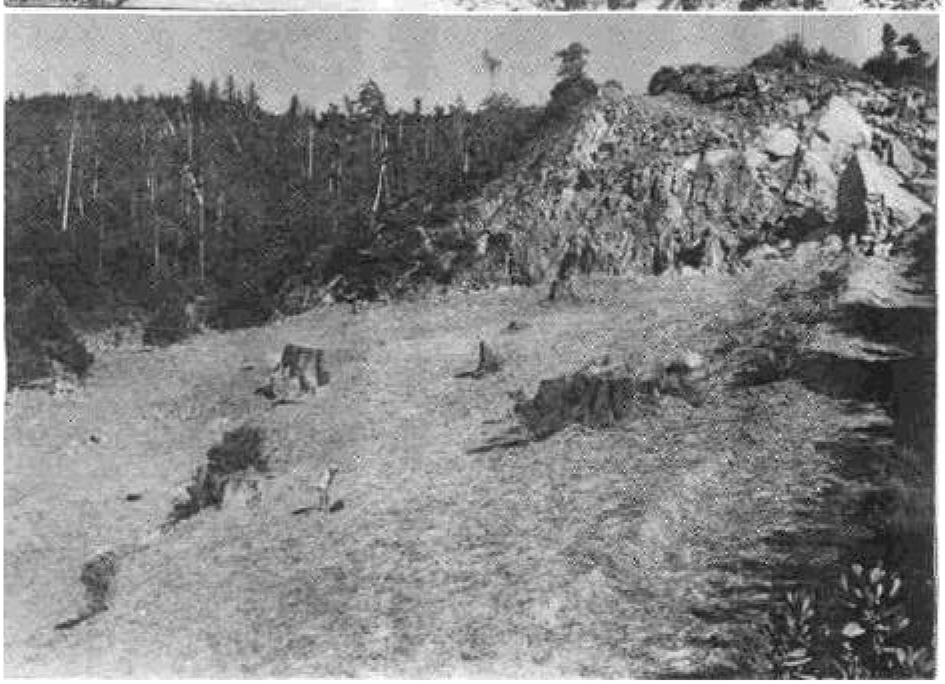


***Figure** 77b.*

3. Stream crossings

Stream crossings are where roads come into closest contact with flowing water. For this reason, it is critical that proper and sufficient erosion control measures be applied to ensure that erosion and sedimentation from culverted fill or bridge sites does not enter the watercourse.

Some stream crossing features are more sensitive to erosion than are others. Problems are most likely to develop at culvert inlets, culvert outlets, through-fill road surfaces, fillslopes, and inside ditches. Erosion prevention and erosion control measures for each of these areas, as discussed below, are commonly employed to limit post-construction erosion. **Regardless of the measures chosen, any successful erosion control technique must be *correctly installed and regularly maintained.***

At culvert inlets, rock armor or flared inlets can be used to protect the pipe entrance from undercutting and erosion (see Chapters IV and V). Trash racks (debris barriers) can be placed upstream from the culvert inlet to prevent culvert plugging and subsequent washout of the entire fill. Drop inlets can be used to prevent culvert plugging in channels with a lot of sediment movement.

Culvert outlets should extend past the end of the road fill and discharge into the natural channel, or a flume or downspout should be attached to the pipe end and extended past the fill before discharging into the channel. Rock armor or other energy dissipation should be used at the outlet of culverts and flumes to prevent erosion by the fast moving flow.

Soils eroded from the road surface can also be delivered to a stream when the road slopes towards the crossing. To prevent this, the road bed can be rock surfaced. If the road is unsurfaced, waterbars or rolling dips should be constructed above the crossing to disperse surface runoff. The road bed can also be insloped through the crossing, so water won't be delivered over the new fill, or the road can be outsloped with a berm to focus road surface water to a single point where it can then be carried down the fillslope in a metal berm-drain. Berms, however, are subject to failure and should only be used on roads that receive regular, wet weather maintenance. Regardless of the methods chosen, road surface runoff needs to be strictly controlled through the crossing.

In addition to controlling road surface runoff, a fail-safe drainage design should be incorporated into every stream crossing fill so that streamflow will not be diverted out of the natural channel and down the road if the culvert plugs with sediment or debris. This requires the road to physically dip down into and out of each stream crossing, even on roads which are climbing across a hillslope. **These changes in road grade at watercourse crossings are key to preventing serious stream crossing failures and gully erosion during large floods.**

Surface erosion on bare fillslopes and on the adjacent cutbanks, can also deliver sediment directly to the stream channel. Most of this erosion comes from raindrop impact and rilling or from shallow failures of saturated, loose or uncompacted soils during winter storms following construction.

Silt fences or straw bale barriers can be constructed on extremely large fills and on steep bare soil areas to retain soil that erodes from the surface. Silt fences do not prevent erosion, they merely trap the sediment and keep it from moving off the site and into a stream. Silt fence barriers and check dams can also be installed in swales and across small ephemeral streams to trap sediment and control erosion. Installation of structures in channels requires careful design and construction, and long-term maintenance. They may have minimal effectiveness or actually cause unwanted erosion if they are improperly installed. Sediment retention dams are generally not an appropriate treatment for larger streams.

The use of silt fence barriers and straw bale check dams have become standard operating practice in many construction sites. To be successful, these measures should be ***correctly*** **applied and** ***maintained*** for as long as they are left in-place. Straw bale structures, for example, need to be replaced every one or two years if they are to remain effective. **However, incorrectly installed and maintained sediment retention structures can cause more erosion than might occur without such structures.** Erosion control specialists (SCS or a private consultant) can assist in the designing and installing special erosion control structures.

The best treatment for surface erosion on slopes less than about 50% is to mulch and vegetate the bare areas as quickly as possible. Surface erosion is immediately controlled on these slopes by applying a thick mulch, or a commercially-available mulching blanket, and by seeding the surface so a healthy stand of grass or legumes develops before major winter storms occur (Figure 78). On steeper slopes and in windy areas, a mulching blanket or a netting may be needed to keep the mulch in place and in contact with the ground surface. Very irregular ground surfaces may also need to be smoothed before applying mulch. Longer term erosion control requires planting or seeding fast growing woody species.

Figure *78. Mulching and seeding are effective methods for controlling surface erosion from bare fill slopes. Mulch protects the soil until the grass and vegetation is firmly established. However, because it decomposes rapidly, straw mulch is effective for only the first year. After that, well established vegetation should provide the needed protection.*

Successful revegetation of stream crossings and other bare soil areas may not always be as simple as throwing out a standard mixture of grass seed. Site conditions such as soil type, exposure, aspect, elevation, summer and winter temperatures, soil dryness or moisture and other site factors may require use of unique or native plant species, special planting techniques, special planting times, fertilizer or soil amendments. A trained wildland botanist, plant ecologist, your local farm advisor, or the SCS should be consulted to see what is recommended for your area.

Notes:

CHAPTER VII: RECONSTRUCTION

A. Introduction to reconstruction

Road reconstruction provides an opportunity to upgrade and improve a road that is substandard in one or more elements of its design. Culverts can be upgraded to current standards, additional drainage structures can be installed, the road bed can be reshaped for improved surface drainage and fills which exhibit instability can be removed and/or stabilized. In general, stream crossings and unstable fill and cutslopes present the greatest challenge to road reconstruction, and the greatest opportunities for future erosion prevention and rehabilitation.

B. Redesign considerations

Only after careful consideration, weighing the economic and environmental benefits against the potential impacts, is it justified to reopen roads that 1) cross unstable hillslopes, 2) were constructed up the axis of a stream channel or 3) would require considerable earth moving with the potential for unacceptable erosion and stream sedimentation. In many cases, temporarily reopening a poorly built road (for a single summer season) may provide substantial positive environmental benefits if subsequent rehabilitation could reduce continuing or future erosion and sedimentation from the old alignment

Decisions about reopening an abandoned road should be made on-site, after having inspected the entire route and reviewing the pros and cons of redisturbing the area. As **a general rule, it is often worth removing even abundant revegetation along the abandoned route if there are substantial erosion prevention projects that could be completed during or following reconstruction.** That is, it is often preferable to remove vegetation than to leave the vegetation intact and not treat potential and ongoing erosion "hot-spots" along the road alignment Removing vegetation and regrowth from the road prism, by itself, rarely causes serious erosion problems. When in doubt, ask for assistance from CDF, CDFG or a wildland erosion control specialist.

Some large, washed-out stream crossings or short sections of road on steep, unstable slopes that have been entirely lost by past erosion or landsliding may not be worth rebuilding. In these cases, it may be preferable to reroute the road around the problem areas with a section of newly constructed road using modem construction techniques and standards.

When reconstruction of an older, existing route has been selected as preferable to new construction, efforts should be made to make improvements in the existing road where ever possible. High maintenance insloped roads can be converted to low maintenance outsloped routes (Figure 79). If the road is to be permanent, all drainage structures should be checked to determine whether or not they are capable of passing the 50-year flood flow, as is currently required of all newly constructed roads used for commercial forestry operations. Any stream crossings that require reconstruction should be redesigned for the higher level of protection, and it is a good idea to replace or remove all intact drainage structures that are undersized for the design storm flow. Humboldt log crossings that were commonly constructed on forest roads from the 1940's through the 1970's should be excavated and permanently removed or replaced with bridges or culverts designed to accommodate 50-year flood flows (Figure 80).

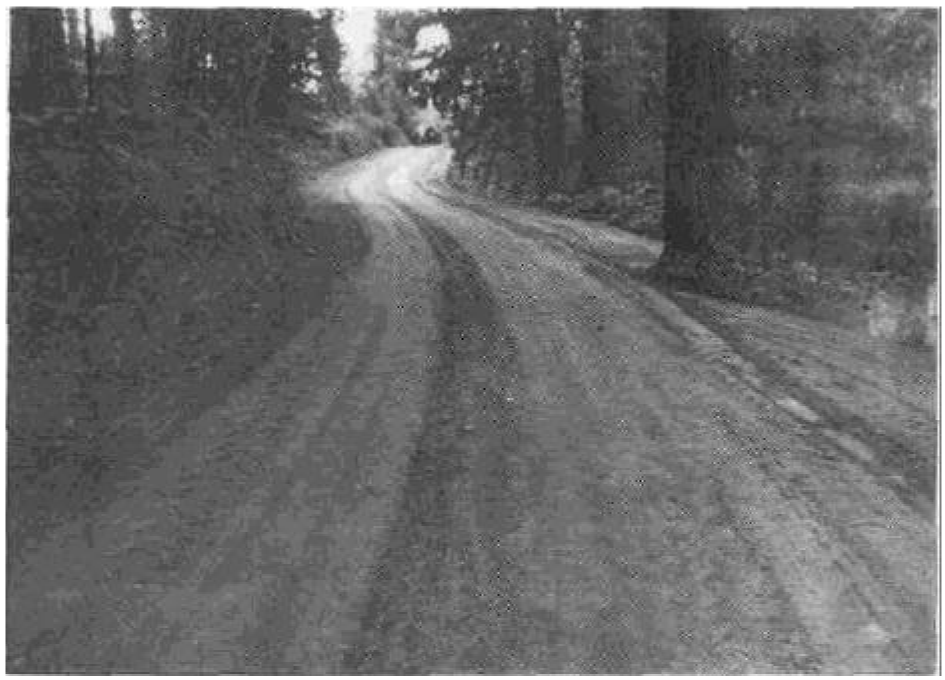


Figure 79. *A former insloped road that was regraded and reconstructed to an outsloped configuration. Outsloping was performed to reduce erosion of the ditch and at the outlet of ditch relief culverts, and to lessen maintenance costs. The road bed was lowered about 8 inches along the outside edge of the fill and spoil was graded to cover the inboard ditch. The road was rock surfaced shortly after the photo as taken.*

Every stream crossing that currently has a high potential for stream diversion should be regraded so that the road dips into and out-of the crossing, thereby eliminating the diversion potential. Regrading the road, and adding rock surfacing, can be performed with a bulldozer in about one hour per site. Culverts should be retro-fitted with trash barriers above the inlets, and with downspouts and/or rock energy dissipation to prevent erosion at the outlet areas.

All reconstruction work should be conducted in a manner that minimizes soil disturbance. Only areas which truly require earth moving should be disturbed. Typically, most of the old road surface will still be intact and require only minor grading to become passable. Ditches and cutbanks should be left undisturbed unless there are specific areas needing repair work. New sidecasting should be avoided in areas of steep slopes, near stream channels or where fills are unstable or oversteepened. As a general rule, landings should not be enlarged by new sidecasting.

Figure 80. Under-designed or unmaintained stream crossings on older roads are prone to failure during large storms. During road reconstruction, stream crossings should be redesigned for the 50-year flood flow. Under-designed culverts and Humboldt log crossings should be removed and upgraded.

C. Reconstruction techniques

The most efficient equipment for road reconstruction include a hydraulic excavator, bulldozer and a grader for final road smoothing. These versatile pieces of equipment can complete reconstruction with a minimum of soil disturbance and loss of vegetation. A standard size backhoe is generally too small to perform the excavations required for stream crossing reconstruction and removal of unstable road and landing fills. Dump trucks may be needed to endhaul slide debris.

Many older roads were initially constructed with an insloped surface and an inside ditch. If conditions are appropriate, the rebuilt road can be converted to a low-impact outsloped surface with rolling dips to disperse road runoff. In ditched road segments, ditch relief culverts and other surface drainage improvements should be made to quickly direct water off the road surface. Many older seasonal and permanent roads have an outside berm which has been created and perpetuated by years of poor grading technique (Figure 81). Water flow off poorly drained roads can often be dramatically improved by outsloping, berm removal and/or other surface drainage improvements.

Washed-out stream crossings present one of the most common obstacles on older roads that are to be reconstructed. Usually, part or all the fill has been eroded and lost downstream because the drainage structure was either too small, not maintained, or not installed.

Washed-out stream crossings are reconstructed just like new ones, with all the same techniques and requirements. If the fill was only partially eroded from the crossing, the remaining material in the channel bottom will likely need to be excavated (down to the original channel bed) before a new culvert is installed. This may include removal of sediment and buried logs.

Figure 81. Surface runoff problems cause by winter use of a bermed, unsurfaced road. Running surface is rutted and this acts to collect runoff and cause additional erosion. Lack of waterbars or rolling dips, together with the graded berm along the outside edge of the road, now acts to keep surface runoff on the road bed. Annual grading can produce an outside berm of soil and rock that should be pulled (graded) back onto the road surface before winter rains.

If a temporary or permanent bridge is to be installed, all the fill should be removed from the old crossing, and the banks should be graded or excavated back to a stable angle. You can often tell that you have removed all the fill material from the former crossing when rounded boulders, old logs and branches, roots, in-place stumps and other features of the original bed and banks are exposed during excavation.

Failed road benches can also present a serious obstacle to reconstruction. In areas of steep inner gorge slopes, failures of the entire width of the road bed can extend all the way downslope to a fish-bearing stream. Sidecastmg into the void in hopes of developing a new road bench at the-same spot will usually result in direct sedimentation into the stream. The resulting fill would also be highly unstable. Road reconstruction where failures have removed most or all of the former road bench are likely to require an engineered solution, such a reinforced fill or a crib wall, and a qualified geotechnical engineer is should be consulted to design solutions for these difficult reconstruction sites.

In many cases, the outer 10-50 percent of the road prism has been lost as a result of fillslope failures or sliver failures, in which only sidecast materials have moved downslope. If there is sufficient road width remaining for vehicles to pass, the unstable area should not be disturbed. Where some additional road width is needed, consider cutting into the inside bank rather than trying to build the fill back out. If fill material has not moved off-site, but is showing signs of pending failure (e.g., scarps displacing or offsetting the road prism), and the failed soils will be delivered to a stream, then the unstable material should be excavated and hauled to a stable storage site for disposal.

Failed or unstable landing fills present similar problems on a larger scale, except that vehicle passage is usually not affected. Unstable landing fills usually result from mixing soils and woody debris together in the uncompacted sidecast around a landing perimeter. The fill face is often oversteepened by continued blading and sidecasting of landing wastes over the outside face of the landing. On steep slopes, these unstable fills and waste deposits can saturate with water and flow great distances downslope and into stream channels. In other cases, failed landing fill material may not be delivered to a stream channel, and only the run-out area is impacted through damage to regeneration and reduced site productivity.

Each unstable landing fill should be evaluated to determine if it threatens downslope stream channels or other important resources. If it does, the unstable fill should be excavated and hauled to a stable storage site for disposal (Figure 82). Often, the inside of the landing is carved into bedrock and can serve as a suitable storage site for excavated fill materials.

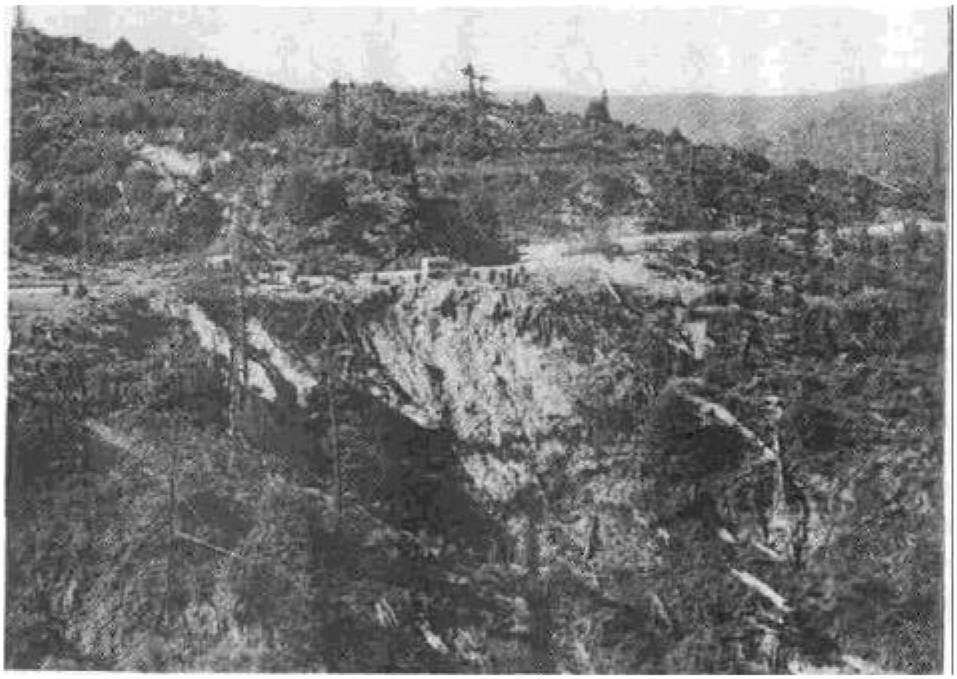


Figure 82. Excess *sidecasting on forest roads and landings that are scheduled for reconstruction should be excavated before it fails and is delivered to a stream channel. Often, potentially unstable spoil can be recognized by cracks and/or scarps along the margins of the road or landing surface.*

Cutslope failures which block the road surface generally represent a less serious erosion problem than fillslope failures, since the road bed may store much of the failed cutbank material and prevent it from moving downslope (Figure 83). Failed materials can usually be excavated off the road bed and hauled to a suitable storage site. Unless slopes are gentle and the road is not close to a stream channel, debris should not be sidecast from the road surface and onto the slopes below. Sometimes the material can be spread over the road bed, thereby raising the road surface and avoiding the need for expensive endhauling.

D. Slash and spoil disposal

Reconstruction of abandoned roads often involves substantial vegetation removal from the road surface. Slash should not be mixed in and sidecast with soil materials. Instead, it can be piled and burned on landings, or windrowed along the outside edge of the cleared fill. Spoil materials generated from road reconstruction (largely from cutbank failures), should be safely disposed in a stable location where it will not erode or enter a watercourse. Spoil disposal techniques are the same as for new road construction (see sections on *construction* and *erosion control, and reconstruction techniques*, above).

Figure 83. Unstable embanks usually pose less of a threat to water quality than unstable fillslopes, but they may still be difficult to stabilize. Soil that is cleared from the road surface should be endhauled or pushed to a stable storage site and not sidecast over the outside edge of the road. In some instances, a slope buttress may need to be designed and installed to prevent further instability and road closures.

E. Erosion control

Erosion prevention and erosion control can actually be improved by road reconstruction. Upgrading or removing stream crossings and removing unstable fills can significantly reduce the likelihood that sediment will be delivered to stream channels. **Even the temporary, single reuse of an abandoned road can serve as an opportunity to perform erosion control and erosion prevention when the road is permanently closed.**

Erosion control during reconstruction of permanent and seasonal roads is largely the same as for new construction. Surface erosion can be minimized by keeping excavation and soil exposure to a minimum, and by retaining as much roadside vegetation as possible. The largest potential source of erosion will be at reconstructed stream crossings. Use of temporary bridges, as well as protective measures at culvert inlets, culvert outlets, road surfaces, and fillslopes will help reduce the potential for accelerated erosion on reconstructed roads (see *construction: stream crossings*, above).

The timing of reconstruction, especially stream crossings, can also help prevent and control unnecessary erosion. Stream crossing reconstruction should be performed during low water conditions. Winter period road reconstruction should only be performed during dry periods and when erosion control measures (mulching, waterbars, etc) can be installed concurrently with road rebuilding. Large sections of road should not be "opened" without performing concurrent erosion control work.

CHAPTER VIII: MAINTENANCE

A. Introduction to road maintenance

Regular road maintenance is essential to protect the road and to prevent environmental damage. All roads used for vehicle travel should be regularly inspected and maintained. **If adequate personnel and financial resources are not available to provide for regular, long term maintenance, roads should be built (or rebuilt) as temporary, and then properly abandoned or closed at the end of the planned operations.** Temporary roads that have been properly abandoned do not need continued maintenance and pose little threat to downstream resources.

B. Inspection and maintenance schedules

Roads and drainage structures along all roads should be inspected annually, at a minimum, prior to the beginning of the rainy season. Inspections should cover culvert inlets and outlets on stream crossings, ditch relief culverts, and road surface drainage such as waterbars, outsloping, and ditches.

In addition to annual, pre-winter road and drainage structure inspections, crews are needed to inspect and perform emergency maintenance during and following peak winter storms. Shovel work at a culvert inlet that is beginning to plug can save the expenditure of thousands of dollars to rebuild an entire stream crossing after it has washed-out.

Some drainage structures are more prone to problems than others. For example, culverts on streams with heavy sediment loads or floating woody debris may be more likely to plug. Landowners or land managers frequently know which culverts in their road system have had the most problems, and which are most likely to plug during a winter storm. In contrast, many culverts, ditches and road surfaces almost never have erosion problems, no matter how severe the winter storm.

This background information can be used to develop a rating system and inspection plan for drainage structures in a watershed. Culverts can be coded by signs along the road. These signs note: 1) where the culvert is located (road name and milepost), 2) the diameter of the culvert, and 3) a number or color coding (e.g., red, yellow and green) that signifies how likely the culvert is to plug, and, therefore, its relative need for inspection during winter storms (Figure 84).

***Figure** 84. Culvert signing is an integral part of developing a culvert and drainage structure maintenance plan. Included at this crossing are the stream name (Puter Creek), the name of the road (5000 Road), the diameter of the culvert (84") and its location (0.6 miles from the beginning of the road). The signing can also be color coded (e.g., green, yellow, red) to indicate whether or not it is prone to plugging or other maintenance needs.*

The number or color coded rating system is based on past maintenance experience with that culvert, and is used in the field to alert inspection crews to which culverts should be inspected first during and following winter storms and floods. **Culvert coding schemes are especially useful for large landowners or companies with many miles of road who may rely on employees unfamiliar with the road system to perform inspections and field maintenance.** Culvert marking is also useful to grader operators, so they can avoid damaging culvert inlets when grading the road or ditch. Over time, each existing drainage structure within an ownership should be inventoried on a master file for quick reference.

C. Maintaining permanent roads

Road maintenance should address the road surface, cutbanks, and fillslopes, as well as drainage structures and erosion control measures. A poorly maintained road surface will channel water, reduce road life and increase erosion and sediment pollution to streams. It may also be difficult **or** hazardous to drive on and damage vehicles and equipment.

The first rule of maintaining a stable road surface is to minimize hauling and grading during wet weather conditions, especially if the road is unsurfaced. But even the best surface can be severely damaged by overuse during wet or thawing ground conditions. Be aware of early signs of road damage. Serious damage to road surfaces begins with loss of road drainage and excess water standing on the surface. Ruts indicate that road strength is deteriorating. Shutting down for several days can save thousands of dollars in road repairs and prevent unnecessary erosion and sedimentation.

Similarly, hauling on a dry road bed in the summer can chum and pulverize road surface material and create thick, loose layers of soil and rock powder (dust). Loose materials can then erode and flow into streams with the first fall runoff. Summer hauling should be accompanied by dust control and watering to maintain the road surface condition. Some dust abatement products can be pollutants, so caution should be used in their application near streams and drainages or where ditch flow leads to a watercourse.

Road surfaces should be graded only when needed to maintain a stable, smooth running surface and to retain the original surface drainage. Over grading results in unnecessary erosion and increases road surface rock wear. Steep road sections will quickly loose their running surface with frequent grading, so *raise the blade wherever grading is not needed!* In addition, grading should only occur when the materials are slightly damp. Road surfaces graded when they are too dry will not compact and will result in subsequent erosion.

Grading should cut deeply into the road surface so loose material will mix, compact and bind with underlying materials. If deep potholes or ruts cannot be graded out, the surface should be ripped and then graded and recompacted to achieve proper binding. Otherwise, individual holes and ruts that are patched will quickly reform in the same locations. Oversized rock fragments that come to the surface during grading can be moved off the side of the road. However, unplanned berms that concentrate runoff during winter rains should not be left along the outside edge of the road.

Over years of hauling and grading, road surfacing materials gradually break down or are inadvertently moved off the side of the road. Steep sections of road and curves experience the highest rates of wear. Often, larger rock fragments are left jutting out of the road bed while the fine materials have been washed or blown away. This makes for a rough ride, and can significantly increase hauling times. When this occurs, it is time for the road to be resurfaced or restored. The road bed should be ripped and new loads of properly graded rock aggregate spread, mixed and compacted into the existing materials. If past grading has piled good surfacing materials along the outside edge of the road, it can be retrieved and worked back into the road bed.

Where inside ditches are used, ditch maintenance is important in order to clear blockages and maintain the flow capacity required to remove surface runoff. Inspecting ditches during periods of high runoff will tell you which ditches need grading to improve their capacity, and which ditches are carrying too much water. Often, nothing more than shovel work at problem spots is required to solved ditch drainage problems. Additional ditch relief culverts can be installed to drain ditches that show signs of erosion or downcutting. Where sections of ditch cannot be drained, such as in a throughout, rock armoring should be installed.

Frequent, routine mechanical grading of ditches is usually unnecessary and can cause erosion of the ditch, undermine cutbanks, and expose the toe of the cutslope to erosion. ***Ditches should be graded only when and where necessary.*** If cutbank slumps have blocked the ditch, clear out the material and move it to a stable storage site. Remove other sediment or restrictive brush and weeds from the ditch only if they create obvious drainage problems that affect the road surface. Do not remove more grass and weeds than is necessary to keep water moving. Vegetation prevents scour and filters out sediment **If the ditch is not a problem, don't "fix" it. Routine mechanical ditch grading should be avoided.**

When "pulling" a ditch (mechanically grading and removing fine sediments), avoid pulling fine silts and clays across or into the surface rock of the road. This unfortunately common practice creates muddy surface conditions and potential for sediment pollution in streams during the next heavy rains. Large amounts of ditch spoil can be windrowed at the inside road shoulder for later endhauling by loader, backhoe and/or truck.

D. Maintaining seasonal roads

Unsurfaced seasonal roads require almost the same maintenance effort as permanent roads, but are much more sensitive to wet weather use. These roads should not be used when wet, and hauling or other intensive vehicle activity should be limited to dry periods when soils retain their maximum natural strength. Road surface grading may be required after each period of intensive use, and prior to the rainy season, in order to maintain proper surface drainage. Dust control and watering during dry summer conditions is almost always necessary during intensive, dry season use to prevent excessive loss of surface materials (Figure 85).

***Figure** 85a. Excessive mud during the winter (a) and excessive road dust during the summer (b) are conditions which directly threaten water quality. Both conditions produce and deliver large quantities of fine sediment to nearby stream channels during periods of surface runoff. This fine material can be especially damaging to fish and fish habitat.*

Figure 85b.

Seasonal, unsurfaced roads can be badly damaged by even occasional use during wet periods when the road bed is soft. Damage to road surfaces can occur almost as easily by a pickup as by a log truck. Traffic control (temporary or seasonal road closures) can be an effective method to protect the road surface, minimize erosion problems and reduce road maintenance costs (Figure 86). However, **the use of gates or other barriers does not eliminate the need for annual and emergency winter maintenance inspection and repairs.**

Figure 86. *There are a variety of ways to close a road to off-season traffic, but it should always be remembered that barricading the road does not by itself prevent erosion along the alignment. Gating closes the road to unauthorized traffic but still allows for winter maintenance and inspections. If barricades or physical barriers are used, they must be removed with heavy equipment before maintenance activities can be performed. They should not be used on roads which have stream crossings since these need to be inspected and maintained during storms.*

In many cases, traffic control may require physically blocking the road. Gates are most often used for this because they provide temporary closure while still allowing access for emergency inspections and maintenance of drainage structures by authorized personnel. Gates should be strong and well anchored to prevent removal by vandals. More permanent alternatives to gates include large berms, ditches(tank traps), logs, stumps or boulders and physical outsloping (Figure 87). These barriers make it very difficult to access and inspect the rest of the road for maintenance needs, and their use should be limited to spur roads with no stream crossings, roads which do not cross or come close to stream channels and roads which have been "permanently" closed.

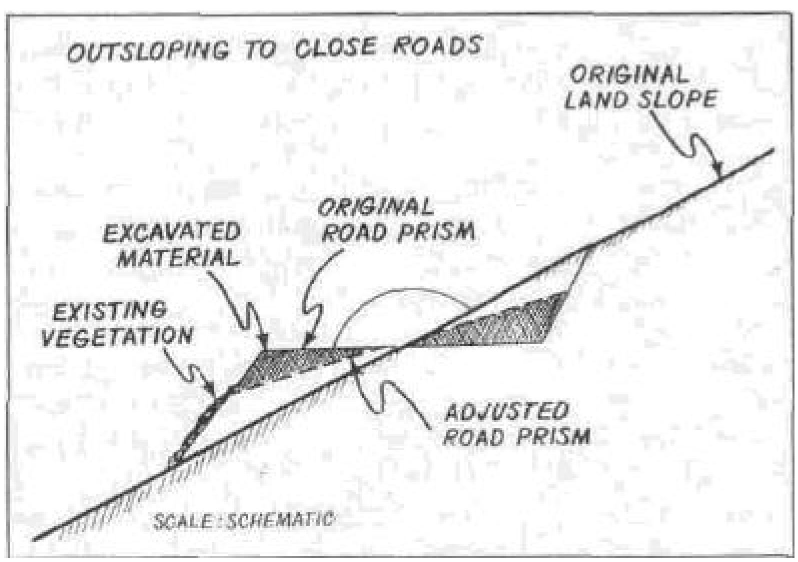


Figure 87a. A more permanent closure method is to outslope the first 100 feet of the road.

Figure 87b. Outsloping should only be used on temporary roads where all stream crossings have first been removed.

E. Stream crossing maintenance

Summer culvert inspections and maintenance is often performed at the same time as ditch maintenance. Culverts also need to be inspected and cleared during peak storms to prevent plugging. Problems found at such times should be corrected immediately, because delay can result in road damage requiring costly road repairs. **The critical component of successful culvert maintenance is to fix problems before complete failure occurs.**

Hand, shovel and chain saw work can take care of almost all culvert maintenance needs (Figure 88). Floatable debris should be removed from the catch basin and material wedged in the culvert inlet or hung up in the debris barrier should be removed and placed where it cannot get back into the watercourse. Sediment deposits that threaten to plug the culvert may need to be excavated. Culvert ends that have been bent or damaged during grading or by falling trees **or** branches should be straightened and re-opened. Outlets that are experiencing erosion should be armored or fitted with a downspout, and culverts that continue to experience overflow problems may need a larger pipe, or a second, overflow pipe installed at the crossing.

Bridges and fords may also require maintenance. Permanent fords that show erosion may need additional rock armor. However, except for emergency repairs, equipment should avoid operating in the flowing water of a ford, and re-armoring may have to wait until low flow conditions, or at least until peak flows subside.

In contrast, riprap and other bridge abutment protection should be repaired as soon as damage is noticed to prevent loss of bridge foundations and approaches. Floating trees and other debris that becomes lodged in the bridge structure should be cut free and removed or floated downstream. When cleaning bridge decks, soil and debris should be scraped to the adjacent road or hauled off. Material should not be dumped, scraped or washed into the stream. This is especially important during low flow conditions in the summer or fall.

Figure 88. *Most culvert maintenance involves cleaning the inlet of sediment or woody debris. This trash rack, built over the culvert inlet, was nearly plugged during a normal winter storm. Without storm maintenance inspections such minor culvert plugging often ends up causing severe gully erosion when the stream/low is diverted out of its channel, or it flows over and erodes the stream crossing/ill.*

All road grading should take material away from the bridge, and loose spoil should be kept away from the stream. If the approaches are persistently muddy during wet conditions, and cause trucks to bring dirt onto the bridge decking, then *the* approaches should be rock surfaced or paved.

F. Maintaining cuts and fills

The key to maintaining cut and fillslopes, including sidecast materials, is to observe and note when and how changes to these features occur. Corrective measures can then be implemented, depending on the problem.

Typical cutslope problems include excessive ravelling, rilling, and slumping which may block the ditch or require frequent ditch cleaning and maintenance. In the long term, it may be necessary to flatten the cutslope, revegetate bare soil areas, widen the ditch (so that it does not plug so easily), install ravel barriers on the slope and at the base, and/or build a retaining structure to contain or prevent slope movement. Often, simply loading the toe of a small cutbank slump with heavy riprap can provide sufficient weight to stabilize the feature. Stabilizing or controlling the movement of larger unstable areas may require analysis by an engineer or engineering geologist

Instability in fillslopes and sidecast materials often shows up on the surface or edge of the road as tension cracks and small scarps along the boundary of the unstable materials. The outside perimeter of landings build using sidecast methods commonly show such developing instabilities. Some settling of newly placed sidecast can be expected, but if movement persists and scarps continue to develop, the unstable materials should be excavated and removed, including organic debris, ***before*** they fail. If the potential instability is perched above a stream channel immediate treatment is usually required (Figure 89).

__Figure 89a.__ Unstable fill along the outside edge of active roads can often be excavated and removed without impeding normal traffic. In photo "a," 12 inch scarps bound unstable fill that threatens to fail on steep slopes above a perennial ***stream.***

Figure *89b. In photo "V" an excavator was used to remove the unstable fill so it could be endhauled to a stable storage location. The road was still sufficiently wide for vehicle traffic after the erosion-proofing work was completed.*

Regular inspection and prevention (including excavation) is the key to maintaining stable fillslopes and sidecast areas. Local slides and slumps in the road bed often occur where material was placed or pushed over groundwater springs or seeps, where the road crosses steep swales, or where rotting roots, stumps or organic debris have been buried. These areas should be closely monitored and require fast action if cracks or scarps develop. Improved drainage (e.g., extra ditches), excavation of unsuitable soils or buried materials, or retaining walls may be needed. Left untreated, these unstable features can fail suddenly and develop into debris flows and landslides that deliver large amounts of sediment directly to downslope stream channels.

G. Winterizing roads

Before winter, all permanent, seasonal and temporary roads should be inspected and prepared for the coming rains. Winterizing consists of maintenance and erosion control work needed to drain the road surface, to ensure free flowing ditches and drains, and to open all culverts to their maximum capacity. On unsurfaced roads, waterbars may be required at spacings dictated by the road gradient and the credibility of the soil (Table 3). Trash barriers, culvert inlet basins and pipe inlets should all be cleaned of floatable debris and sediment accumulations. Ditches that are partially or entirely plugged with soil and debris should be cleaned and heavy concentrations of vegetation which impede ditch flow should be trimmed. This is also the best dme to excavate all unstable or potentially unstable fills and sidecast which could fail and be delivered to a watercourse during the coming winter. Once seasonal and temporary roads have been winterized, they should be gated and closed to "non-essential" traffic.

H. Spoil disposal

If excavations, grading and culvert basin cleaning and maintenance produces excess material, it should be stored locally or hauled away. Spoil may be feathered over the road, but on permanent roads, excess fine material may produce unwanted muddy conditions after the first rain. Spoil material should be hauled to a stable site safely distant from streams, contoured to disperse runoff and stabilized with mulch and vegetation. Excess spoil from maintenance activities should never be sidecast near streams. Berms of excess spoil along the road shoulder should be removed or frequently breached prior to the rainy season.

Notes:

CHAPTER IX: CLOSURE AND ABANDONMENT

A. Introduction to road closure and abandonment

There are many reasons for closing or proactively "abandoning" a forest or ranch road, most of which involve excessive maintenance costs, lack of continued need or continuing water quality problems (Table 25). Not all roads need to be part of the permanent or seasonal road system. For example, temporary roads are used once, and then "put-to-bed" until they are needed again. In addition to newly built temporary roads, there are many miles of existing roads that may no longer be needed, and older abandoned roads that are now overgrown. The same techniques can be used to "erosion-proof these older roads to prevent future erosion and sediment yield, and, as an added benefit or incentive, save the work and expense of continued maintenance.

Table 25. Conditions commonly leading to road closure
1. Roads constructed for temporary access (designated temporary roads)
2. Spur roads which are no longer needed for management for the next few years or for many years (e.g., all timber has been cut)
3. Roads with excessively high maintenance costs
4. Roads which have persistent erosion and water quality problems, often located in areas of extremely credible soils
5. Roads crossing extremely steep slopes or inner gorge locations where landsliding risk is high and sediment could enter stream channels
6. Roads crossing slopes with high or extreme landslide risk or on-going landslide activity caused by incompetent bedrock or unstable soils
7. Roads exhibiting potential for large fillslope or cutbank failures, often showing tension cracks and scarps in the roadbed
8. Roads built with excessive sidecast or fill in unstable locations or perched above stream channels
9. Old roads built in, along or immediately adjacent stream channels or up narrow stream channel valleys
10. Old, abandoned roads which have overgrown with vegetation and now have washed-out stream crossings and/or fill failures

Roads may be divided into four activity classes:

Active roads are part of the overall road network that *must* be actively inspected and maintained. These maintenance methods have already been described above.

Inactive roads are those needed only infrequently, for fire control, tree thinning or other intermittent forest or ranch activities. These roads remain largely unused for most of the year, or for several years in succession. There is a tendency to not maintain these routes because they are not often used, have low traffic volumes, and may only be used intermittently for administrative purposes. However, **all drainage structures on inactive roads must still be inspected and maintained because they are just as likely to plug and fail as those on more actively travelled routes.**

Temporary roads are constructed or reconstructed for a single entry access to an area, such as for harvesting an isolated stand of timber. These temporary roads are "put-to-bed" following their use, with stream crossings being removed using the techniques described in Chapter VI. Forest practice regulations for state and private lands currently require such preventive practices to stabilize temporary roads when they are closed.

Abandoned roads were previously a part of the active road network, but are no longer used. Many are now overgrown. There are thousands of miles of these abandoned roads on private forest and ranch lands in the state. They may have been abandoned because they were no longer needed, or because they cross unstable areas, require excessive maintenance or cause persistent environmental damage. Most have drainage structures which are in disrepair and are no longer being maintained. **These abandoned roads represent one of the greatest future threats of non-point source pollution from roaded, managed wildland watersheds. Landowners and resource managers should work aggressively to inventory and proactively treat these potential sources of erosion and sedimentation.**

Good land stewardship requires that all roads designated as part of a drivable road network be regularly inspected and maintained to protect water quality, regardless of how frequently they are used. Inactive and temporary roads that contain culverted stream crossings and other drainage structures *require* inspection and maintenance, and they should not be abandoned without first employing proper road closure techniques.

Any road that is not regularly inspected and maintained should be "put-to-bed" so they will not have the potential to impact streams and water quality. Roads should never be abandoned by simply blocking them off or letting vegetation take over without first "erosion-proofing" drainage structures and performing proactive erosion control work along the road alignment.

B. Techniques for road closure

It is no longer enough to close roads by simply closing a gate or blocking a road, because these actions will not prevent future road failure and future water quality problems (Figure 90). Specific techniques, described below, are available to successfully prevent road- and landing-related debris flows, to prevent or correct stream diversions (the leading cause of serious gullying in many areas), to prevent stream crossing washouts and fill failures, to dewater gullies and landslides fed by road runoff, and to control surface erosion (rilling and ravelling) from abandoned road surfaces and fillslopes.

Figure 90. *Gating a road closes it to unauthorized traffic, but does nothing to protect the road from erosion. Scarps in the road fill behind this gate signal a slope failure that threatens to deliver sediment to an adjacent fish-bearing stream.*

Closing a road does not imply that every foot of the road needs intensive treatment to prevent future erosion. **Rather, the goal of proactive road closure is to aggressively treat only those segments of road which have a potential to generate erosion and to yield sediment to stream channels.** Segments of road which pose no risk of sediment delivery can be left intact and receive only minimal road drainage improvements. When the road is again needed to provide access to the area, it can be reconstructed with minimal effort.

Planned, systematic road closure can be an inexpensive and effective technique for minimizing long-term resource damage caused by roads built in steep areas and can prevent large scale damage to road alignments that require costly repairs if the road is to be reopened for future use. It also provides land managers with an opportunity to permanently prevent or control the majority of post-construction road-related erosion and its associated on-site and downstream impacts. In addition, implementing technically sound road closure practices also minimizes structural damage to widespread, expensive forest and ranch land road networks that cannot be economically maintained for the long time period between harvest rotations or other land uses.

There is little difference between treatments that are meant to permanently close a road and those designed for temporary closure. When a temporary road is built, or when a permanent or seasonal road is to be closed and taken off the active road network, erosion prevention work should be performed so that continued maintenance is not necessary. All closed roads should be "erosion-proofed" by excavating stream crossings and removing culverts, excavating unstable road and landing fills, treating the ditch and road surface to disperse runoff and prevent surface erosion, and planting bare soil areas.

The goal of road closure is to leave the road so that little or no maintenance is required for stability while the road is unused. Heavy equipment used for road closure typically includes a hydraulic excavator (a standard backhoe is too small and generally not versatile enough to effectively perform road closure tasks), a bulldozer (D6 to D7 size, with hydraulic rippers for decompacting rocked roads) and dump trucks (when needed for endhauling spoil and debris to stable storage sites).

Typical road closure treatments are described below.

1. Stream crossing excavations

All stream crossings on temporary or abandoned seasonal and permanent roads need to be completely removed *before* the first winter period following their installation or closure (if not, they should be capable of passing the 50-year flood flow for that channel).

Removing a stream crossing involves excavating and removing all materials placed in the stream channel when the crossing was built. Fill material should be excavated to recreate the original channel grade (slope) and orientation, with a channel bed that is as wide or ***slightly wider*** than the original watercourse (Figure 91). If the channel sideslopes were disturbed, they should be graded ("pulled" or excavated) back to a stable angle (generally less than 50%) to prevent slumping and soil movement. The bare soils should then be mulched, seeded and/or armored to minimize erosion until vegetation can protect the surface, and the approaching road segments should be cross-road drained to prevent road runoff from discharging across the freshly excavated channel sideslopes.

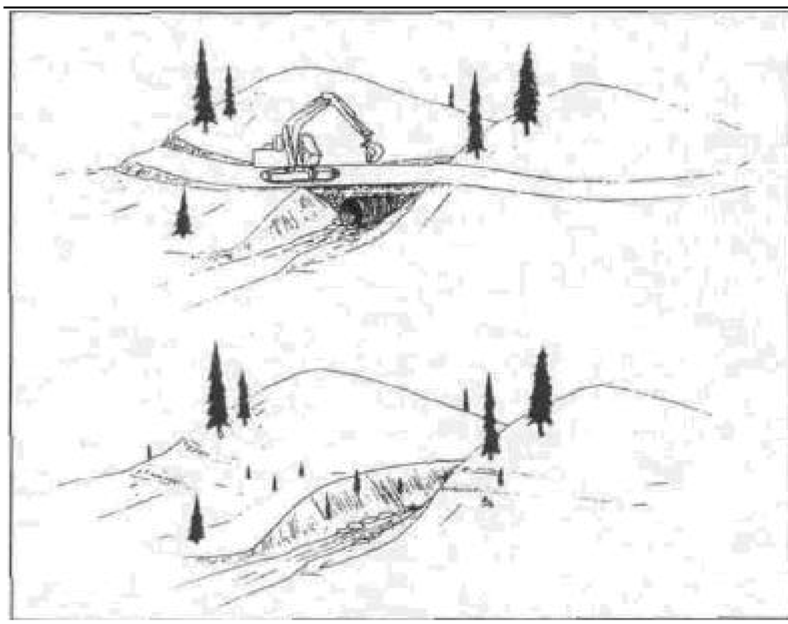


Figure 91. *On roads that are* ***to be*** *closed, all stream crossing culverts and fills should be removed. Stream crossing excavations are best performed using an excavator. Spoil can usually be stored on the road bench adjacent the crossing provided it is placed and stabilized where it will not erode and enter the channel (Furbniss, et.al.,1991).*

Procedures for removing crossings on abandoned, permanent or seasonal roads are similar to those used on temporary roads. Both culverted and unculverted stream crossings (e.g., culverts and Humboldt log crossings) should be completely excavated or removed so that no soil materials are left in or next to the channel following road closure. **It is not enough to simply excavate and remove the culvert; the entire fill must also be excavated.** As with temporary stream crossings, the excavation should extend down to the level of the original channel bed, with a channel as wide or wider than the original channel. Channel sideslopes should be sloped back to a stable angle and spoil material removed to a stable storage site. Erosion control measures, such as seeding, planting and mulching, should be applied to prevent subsequent surface erosion (Figure 92).

Figure 92a. *Stream crossing on a temporary road before (a) and after (b) it was excavated and the road was closed (person is standing over the axis of the stream channel}. Since the road bed is still intact everywhere but at the stream crossings, it can be reopened by simply reinstalling the culverts. In the meantime, no road maintenance is required.*

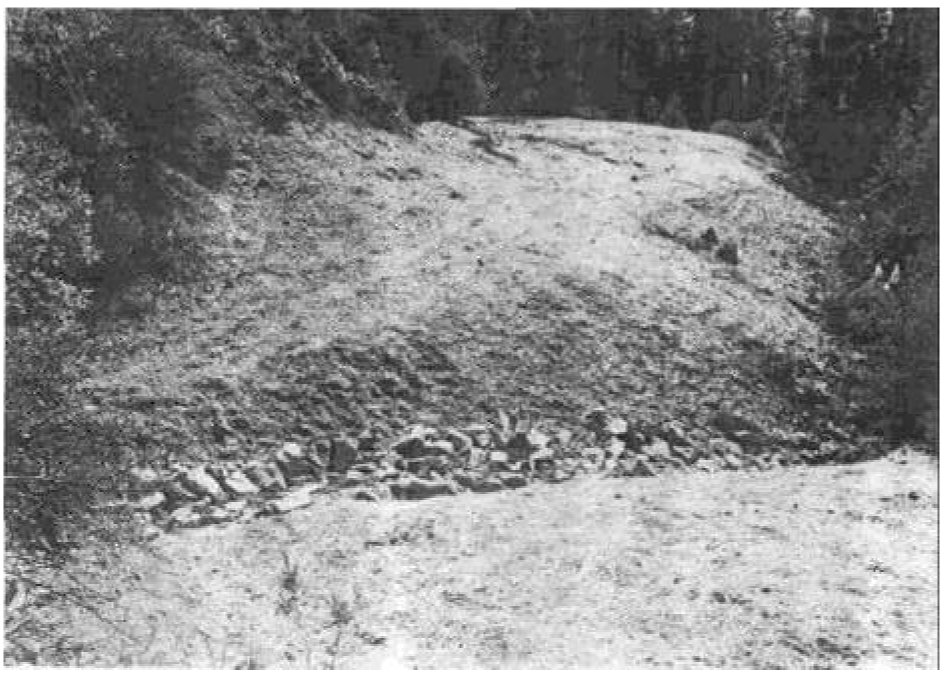


Figure 92b.

2. Treatment of unstable areas

Any unstable or potentially unstable road or landing fills (or sidecast) should be excavated and stabilized so material does not fail and enter a watercourse or destroy down-slope vegetation. Such areas include sidecast and fill materials which show recently developed scarps or cracks (Figure 93). These sites occur most often 1) around the perimeter of landings, 2) on sidecast constructed roads built on steep slopes, 3) where roads have been built on steep slopes over springs or seeps, or 4) where roads have been cut into steep headwater swales or "dips" in the hillside. Cribbed fills which were installed at unstable areas during road construction or reconstruction should also be removed and outsloped if they could fail into a downslope stream channel.

Figure 93a. *Excavation of unstable landing fill on a road scheduled for permanent closure: (a) before excavation.*

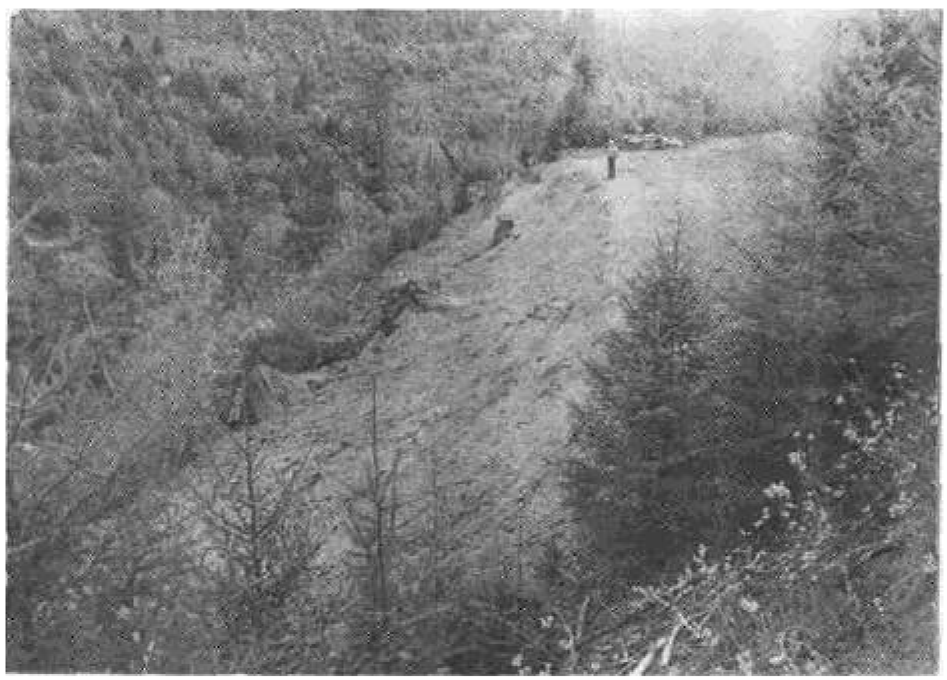


Figure 93b. *(b) after excavation.*

Potentially unstable road material that is likely to enter a Class I, II, or III watercourse or damage reproduction or other sensitive resources should be excavated and treated during road closure operations. All spoil material should be placed in a stable location and revegetated. Spoil disposal sites include the cut portion of closed roads and the inside portion of landings and turnouts.

Cutbank failure materials are often completely caught and stored on the adjacent road prism. For this reason, cutbank instabilities often do not need the same amount of "erosion-proofing" and stabilizing as is needed on fillslopes and stream crossings. Some buttressing, revegetation and upslope drainage control may be required to prevent larger failures and erosion that could affect water quality. No active ditches or diversions should be left at the base of an unstable or ravelling cutbank on a closed road. In fact, ditches should not be left open and functioning when a road is closed because all ditches are likely to eventually become plugged with sediment or vegetation and cause water to be diverted onto the road surface.

3. Road surface runoff and other drainage structures

Roads that are to be closed and unmaintained should have adequate, self-maintaining surface drainage so that the road surface is stable and will not erode and deliver sediment to a stream.

Most temporary roads should have been built as outsloped roads, and any ditched segments of roads to be closed should be outsloped or drained with cross road ditches during closure operations. Outside road berms should be removed to encourage continuous drainage off the road surface.

Inside road ditches should be eliminated when closing temporary and abandoned roads so that water is not diverted and gullies do not form. Drains should be made deeper than standard waterbars and extend all the way from the cutbank to the outside edge of the road in order to intercept all ditch flow. On steep sections of road (>10%) cross drains should be skewed at 45% to the road alignment (instead of the usual 30%) to reduce the threat of erosion at the inlet (Figure 94). Since inside ditches will be breached and no longer carry runoff, ditch relief culverts are no longer needed on closed roads and can be either removed and salvaged or left in-place.

Cross-road drains should be placed frequently enough such that flow through individual drains will not require the use of rock armor energy dissipators to prevent erosion at the outlet. However, cross drains that carry spring flow or flow from small upslope gullies may require armoring at their outlet and should be discharged into vegetation to filter water and sediment before runoff reaches a stream.

Figure 94. *Insloped and ditched roads, especially those with springs and seeps on the cutbanks, should have cross road drains constructed to provide drainage across the alignment. Drains can be installed at wet areas along the cutbank, or at intervals frequent enough to prevent gullying of the roadbed between drains.*

Ripping and planting abandoned roads can reduce runoff and erosion, and greatly increase the amount of forest and ranch land in production. Ideally, the abandoned road surface should be scarified (ripped to a depth of 15-24 inches), outsloped at least 4% more than the road grade, waterbarred, seeded and planted to control surface runoff and erosion (Figure 95). Wet, spring-fed cutbanks along outsloped roads should not be covered with spoil, and roads that are not outsloped should have frequent cross-road drains installed. Tree growth on compacted or rocked road surfaces is generally much slower that on adjacent, uncompacted sites unless the roadbed is mechanically ripped. Ripping is most effective in breaking compaction and promoting tree growth when it is conducted with a winged subsoiler that lifts and shatters the soil. Ripping can also be performed using hydraulically operated chisel teeth mounted on the back of a large tractor, although several passes may be required to disaggregate the entire roadbed.

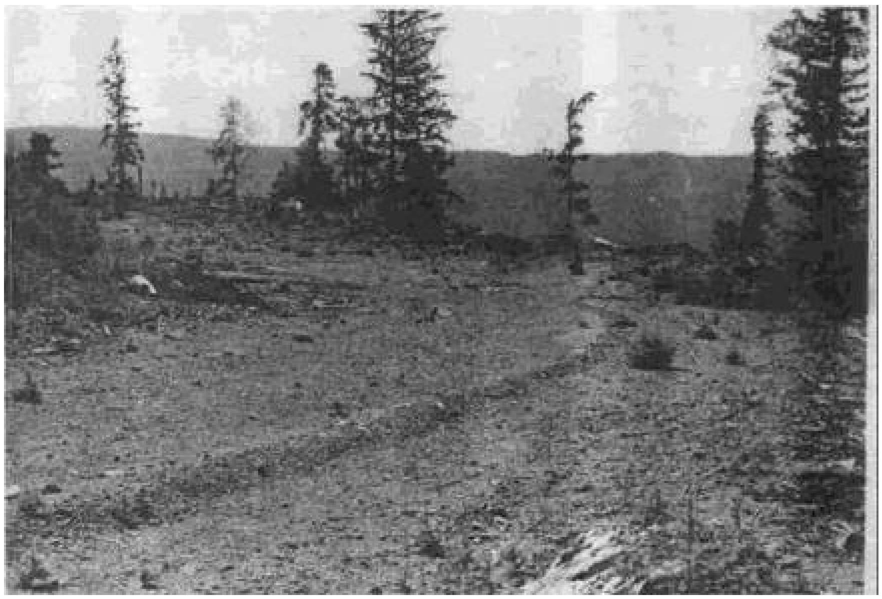


Figure 95a. *On forest roads which are to be formally closed, rather than just "abandoned," the roadbed can be returned to forest production by ripping and disaggregating the surface and then planting with trees. Photos "a" and "b" show a road/landing before and after decompaction. This simple, inexpensive process also helps reduce runoff from compacted areas.*

Figure 95b. *"After.'*

4. Erosion control

Most erosion control work along closed roads is accomplished by 1) the physical excavation of stream crossings, unstable fills and landing sidecast, 2) installation of cross-road drains, 3) road ripping, and 4) local road outsloping. These techniques are usually performed by heavy equipment. Other hand-labor erosion control and revegetation practices that may be of use include mulching, installation of energy dissipation (e.g., rock armoring and woody debris), seeding and planting.

The banks of all excavated stream crossings, as well as all bare soil areas immediately adjacent a watercourse, should be mulched with straw (3,000 to 5,000 Ibs/acre) or another mulching product. On slopes over about 45%, or where high winds are common, mulches will need to be tacked, punched or secured to the ground surface to hold them in-place and against the ground. Straw can be punched into loose soil using shovels, crimpers or a spiked roller, or held onto the surface using a netting or a "tacking" spray. Mulches can also be purchased in rolls, in which the mulch is bound between fine plastic netting, which can then be rolled out and secured or "stapled" to the ground.

If rock armor materials are plentiful, the channel-bottom of excavated stream crossings can be armored with well graded rock to minimize subsequent channel downcutting or widening. However, rock armor should not be necessary for erosion control *if* all fill material is removed from the crossing and the original channel profile and sideslope configuration are reconstructed by excavation. If the natural channel armor was not removed during initial culvert installation, it should be sufficient to protect the channel from downcutting.

Rock and/or woody debris can be placed at the outlets to cross-road drains that are expected to carry substantial spring-flow. Rock armor is generally preferable because it is more permanent and adjusts its position when there is minor channel downcutting.

5. Revegetation

Vegetation is the ultimate, long-term erosion control agent. However, because it takes time to grow a thick, effective cover, some physical erosion control measures (such as straw mulch or "silt fences") are often needed for the first year or two following road construction or closure. Seeding with grass and legumes reduces surface erosion and can improve soil physical condition. Planting trees and shrubs adds longer lasting vegetative cover and provides stronger root systems which enhances slope stability. Within their appropriate range, conifers, hardwoods and other tree species provide for long term land stability and erosion control.

Seeding with grass and other fast growing species can be used to protect slopes from raindrop and rill erosion, if it is planted and grows to provide a thick cover before the first fall rains. Planting is best conducted immediately after the surface is disturbed. The rough surface provides miniature traps for seeds, fertilizer and rain water, creating a favorable environment for seed germination and growth. Mulches increase seedling establishment by improving germinating conditions and controlling erosion until the plants become established.

The two basic methods for spreading seed are dry seeding and hydraulic seeding. Each method is suited for specific ground conditions (Table 26). Dry seeding and fertilizing along small roads is often done with cyclone-type rotary seeders. This method is usually done by hand for road-related applications, but may also be performed by truck and aerial application for larger jobs. Hand seeders are typically restricted to moderate or gentle slopes and can shoot seed and fertilizer from 15 to 20 feet. Drilling seed into the planting bed ensures an even distribution, but may not be possible due to the steepness of many road cuts and fills. In hydraulic seeding (hydro-seeding), seed, mulch (or binder) and fertilizer is applied in a water-based slurry from a pump truck or portable trailer. Hydroseeding may be necessary for planting 1:1 or steeper slopes, where the seed must be "tacked" to the slope because of high ravel or erosion rates.

Table 26. Guidelines for seeding method selection[1]

Site conditions	Sample situations	Seeding method
Steep (>50%) or windy slopes, high to extreme erosion hazard	steep cutbanks and fillslopes	hydraulic seeding with a sprayed or tacked mulch
Moderate (30-50%) and steep slopes, medium to high erosion hazard	moderate and steep cutbanks and fillslopes; stream crossing fills and bridge sites	hydraulic seeding or dry seeding with a mulch
Gentle and moderate slopes, medium to high erosion hazard	cutbanks, fillslopes and spoil disposal sites not near a watercourse	hydraulic seeding or dry seeding; mulch where needed
Gentle and moderate slopes, low to moderate erosion hazard	cutbanks, fillslopes and spoil disposal sites not near a watercourse	dry seeding; mulch if needed to improve revegetation

[1] *Modified from B.C.M.F., 1991*

Regardless of the method selected, seed must be evenly distributed to result in a continuous plant cover. Seeding onto a roughened soil surface or thinly covering the seed with soil ensures good germination. In dry climates or in soils with poor water holding capacities, broadcast seeding may yield poor results unless the seeds are covered.

Severely disturbed sub-soils and cutbank exposures are usually infertile, and fertilizer applications containing nitrogen (N), phosphorous (P), potassium (K), and occasionally sulphur (S) may be needed for successful grass-legume establishment and growth. Fertilization rates vary according to the level of nutrients needed for establishment Soils can be tested for nutrient content before fertilizer mixes are prepared. More often, commercial mixes are used which provide all the necessary nutrients for plant growth.

Parent materials and subsoils are always deficient in nitrogen. A common recommendation is to broadcast ammonium phosphate sulfate fertilizer (16-20-0) at the rate of 500 Ibs/acre at planting time. This provides sufficient nutrients for the first growing season. Critical sites (e.g., stream crossings) may need to be refertilized after 3 to 5 years to maintain plant vigor and an adequate ground cover. Planting legumes in infertile soils is often suggested because they are able to grow without nitrogen fertilizer. Before seeding, legume seeds require inoculation with a nitrogen fixing bacteria which then grows on its roots.

Typically, a combination of 2 to 5 species, including sod forming grasses, bunch grasses and legumes, is used for erosion control. Legumes are included for their deeper roots and nitrogen fixing capability. Seed mixes suitable for an area depend on the soil and climatic conditions of the site. Seeding rate depends on the desired species mix, seed weight and viability of the seed stock.

The *California interagency seeding guide for erosion control plantings (1986)* is a short publication which describes general seed mixes which have been found to be useful for erosion control within the mediterranean climate of California (Table 27). It describes seeding rates and environmental requirements for a number of proven perennial and annual grasses, annual clovers and vetch, one shrub and several flower species, and outlines the steps to successful plantings.

The most important considerations in seeding are timing of application, even distribution of seed and covering the seed with soil. Planting at the wrong time is the most common reason for seeding failure. Seeding must be done early enough in the growing season so that an adequate ground cover can become established before the critical winter period. Seed application should begin immediately following heavy equipment operations and soil disturbance, and a minimum of 6 weeks before periods of drought or damaging frost. Fall seeding is best in areas with summer drought.

Planting and seeding for erosion control requires the development of a rapid, persistent and continuous plant cover. Annual grasses often produce the quickest protection, but are only a temporary solution and can sometimes actually impede the growth of other plants. Perennial grasses are slower to establish but provide better root systems than annuals. Perennials may also have difficulty competing and surviving when seeded with annual grasses in the same mix. Annual legumes provide nitrogen to the soil as they grow, but they too are relatively slow to grow and may not compete well with heavily seeded annual grasses. Shrubs and trees are slow to provide a ground cover, and may not compete well when seeded with other species, but they often provide the best long term stability to a disturbed road site. Native shrubs and trees will seed naturally to many disturbed sites in forested areas. Planting or transplanting can be used to speed their return.

Utilizing a mix of seeds increases the likelihood that one of the plant species will find local conditions favorable and produce a good plant cover. If a commercial seed mix is used, it is important that plants known to be effective in erosion control be found in the mix, that the species are adapted to grow in the local environment, and that the species are compatible in mixtures (i.e., that one doesn't out-compete the other). In general, seed mixes should be kept simple. The grass-legume ratio, by live pure seed, should be about 70:30 in humid regions and 80:20 in dry regions. It is a good idea to consult your local Soil Conservation Service office or Resource Conservation District for seeding recommendations for your specific area and need.

Following seeding, all bare soils on newly constructed, reconstructed and closed roads should be planted with trees and/or other woody vegetation. In addition, the slopes and channel banks adjacent to excavated stream crossings can be planted with willow, alder or other riparian tree species (Table 28) and shrub species (Table 29) compatible with the local site conditions. These woody species take longer to become established, but they provide the long-term ground cover and soil binding needed for effective erosion prevention, soil development and slope stability on these heavily disturbed sites.

Table 27. Species, growth characteristics and minimum seeding rates of plants know to be effective in controlling erosion on California forest and ranch lands[1]						
Species	**Characteristics**	**Planting**	**LBS/Acre pure live seed[2]**		**Minimum annual rainfall (in)**	**Growth rate/ longevity**
			Good seedbed[3]	**Poor seedbed[4]**		
Annual Grasses (usually fast growing, adaptable and competitive)						
Annual or Wimmera-62 ryegrass	fast, winter growing, short-lived grass, requires fertilization to persist, very competitive (to the detriment of other seeded plants)	never plant with perennial grasses, legumes or flowers; should be less than 50% of any annual grass mix	22	50	12	fast, short-lived
Barley	winter grain, grows fast and tall,	may be seeded at 100 Ibs/acre without being overly competitive	150	200	12	fast, temporary
Blando brome	winter growing, self seeding grass, very adaptable to various climates	use in any proportion with annual grasses, keep to less than 70% when planted with legumes; should not be planted with flowers or perennial grasses	15	50	12	fast, reseeds
Panoche red brome	winter active, self-seeding grass, common in low rainfall areas; very drought tolerant	best if planted alone in droughty areas; in wetter areas may be used as 25% mix with legumes, flowers or shrubs	10	20	7	fast, reseeds
Zorro annual fescue	winter growing, early maturing, self seeding grass; very drought tolerant; good in low-fertility, acid soils	is compatible with perennial native grasses and shrubs, can comprise 70% of mix with annual legumes and 25% of mix with flowers, legumes and shrubs	10	20	10	fast, reseeds

Table 27. (continued)						
Species	**Characteristics**	**Planting**	**LBS/Acre pure live seed[2]**		**Minimum annual rainfall (in)**	**Growth rate/ longevity**
			Good seedbed[3]	**Poor seedbed[4]**		
Perennial Grasses (usually restricted to sites requiring deep rooting and/or minimum maintenance; are slow growing in the first year and do not compete well with most annual grasses; flowers or annual grasses may constitute up to 50% of a mix with perennial grasses)						
Berber orchardgrass	long lived, drought tolerant bunch grass; good for dryland areas	Palestine orchardgrass may be substituted as second choice, but no others will survive without irrigation	10	20	16	medium
Luna pubescent wheatgrass	long lived, fast maturing, sod forming, winter active grass	often used on deeper soils such as fillslopes, including serpentine soils	20	40	16	slow
Mission veldtgrass	long lived, densely tufed bunchgrass	outstanding in coastal sandy soils	30	40	14	slow
Smilo	long lived, drought tolerant bunchgrass	best on well drained soils that once grew chamise in brushlands; best stands obtained after fire	10	20	16	slow
Annual clovers and vetch Annual clovers are used because of their ability to provide their own nitrogen. This make them suitable for low fertility areas that would otherwise need fertilizer. The seed should be inoculated with nitrogen fixing bacteria prior to planting. May be seeded alone or in mixes.						
Rose clover	self seeding legume	used of slightly acid soils	20	30	10	medium, reseeds
Lana wollypod vetch	widely adapted, self seeding legume	useful for providing wildlife food and habitat, alternates should be used in fire hazard areas	45	60	14	medium, reseeds

Table 27. (Continued)

Species	Characteristics	Planting	LBS/Acre pure live seed[2]		Minimum annual rainfall (in)	Growth rate/ longevity
			Good seedbed[3]	Poor seedbed[4]		
Shrubs Most shrubs must be transplanted from cans or liners; these may be directly seeded.						
Australian saltbush	low growing, semi-prostrate perennial; plant is drought and alkali tolerant	—	15	20	10	slow
Duro California buckwheat	widely adapted and drought tolerant	used extensively in road side seeding, is adapted to much of the state	10	20	10	slow
Flowers Flowers are useful for short duration cover on sites with low erosion potential; seldom persist for more than 1-2 years; do not plant with annual grasses and do not fertilize with nitrogen. Poppies and lupine have the record for persisting the longest of most flowers.						
California poppies	can be planted on most weed-free soils; will not compete with grasses or weeds	—	5	20	10	slow
Lupine	adapted to a variety of soils; lupine should be inoculated with bacteria before seeding	several varieties *of Lupinus* may be planted	5	20	10	slow

[1] *from California Interagency Seeding Guide for Erosion Control Plantings. Plants are known to control erosion in the mediterranean climate of California. Specific soils and rainfall may limit the use of each species. Suggested seeding rates are minimum; consider increasing rates as difficulty of site and climate increase.*

[2] "pure-live seed" = % germination x % purity divided by 100.

[3] "Good seedbed" = seed covered with soil, slopes 3:1 or flatter, straw secured to slope surface at 1.5 to 2 tons/acre.

[4] "Poor seedbed" = poor soil, steep slopes, no seed coverage (no mulch). May be hydroseeded.

Table 28. Recommended tree species for revegetating riparian zones[1]			
Riparian species (common name)	**Coastal**	**Interior valley**	**Interior foothill**
California buckeye		X	X
Bigleaf maple	X	X	
California box elder		X	
White alder	X		X
Red alder	X		
California black walnut		X	X
Western sycamore	X	X	X
Fremont cottonwood	X	X	X
Coastal live oak	X	X	
California black oak			X
Valley oak		X	
Interior live oak		X	X
Red willow	X	X	X
Black willow	X	X	X
Sandbar willow	X	X	X
Oregon ash	X	X	X
California bay	X		
Dogwood	X	X	X
Wax myrtle	X		

[1] *From C.D. F.G.. (1992) When selecting species/or a revegetatlon project, those species found in similar environmental conditions near to the project site should be preferred.*

Table 29. Recommended shrub species revegetation for riparian zones [1]			
Riparian species (common name)	**Coastal**	**Interior Valley**	**Interior Foothill**
Elderberry	X	X	X
Brewers saltbush	X	X	
Coyote brush	X	X	X
Mule fat	X	X	
Ceanothus spp.	X	X	X
Western redbud	X		X
Mountain mahogany			X
Button bush	X	X	
California buckwheat	X	X	X
Toyon		X	X
California coffeeberry		X	X
Red flowering current			X
California wild rose		X	X
California blackberry		X	X
Black sage			X
Squaw bush		X	X
Prunusspp.	X	X	X
Rims spp.	X	X	X

From C.D.F.G. (1992) When selecting species for a revegetation project, those species found in similar environmental conditions near to the project site should be preferred.

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GLOSSARY

Terms

Abandoned road - a road which is no longer maintained. An abandoned road may or may not still be driveable and may or may not be overgrown with vegetation (see also *road abandonment)*.

Abney level - a hand-held instrument used to measure slopes and vertical angles in the field.

Abutment (bridge) - a solid foundation on each stream bank on which the ends of a bridge are secured. Naturally occurring rock outcrops may serve as abutments, but most commonly abutments are made of cement sills, logs or piers installed by man.

Accelerated erosion - erosion which has been caused directly or indirectly by human activities or land management. Accelerated erosion is typically thought of as erosion which is not "natural" or that which is excess of that whic h would have naturally occurred.

Active road - a road that is pan of the overall road network that needs to be actively inspected and maintained.

Altimeter - a hand-held instrument which can be used to determine elevation or altitude in the field.

Anadromous fish - fish that are born and rear in freshwater, move to the ocean to grow and mature, and return to freshwater to reproduce. Salmon, steelhead and shad are examples.

Angle of repose - the steepest slope angle at which a material will freely stand without failing or sliding downslope. The angle of repose of material without cohesion, like loose sand, is about 33 degrees. For material with some cohesion, the comparable term is called the angle of internal friction. Slopes which are steeper than the angle of repose or angle of internal friction are likely to be unstable.

Archaeological site - a geographic locale that contains the material remains of prehistoric and/or historic human activity.

Aspect - The direction a slope faces with respect to the cardinal compass points.

Backcasting - a road construction technique which utilizes a hydraulic excavator to cut a wide bench in front of the machine and below the centerline of the new road, while placing the excavated soil on the bench behind as the new subgrade.

Balanced benching - a road building method used on gentle or moderate sloping land in which material excavated during road construction is used to build the roadbed and fill the low spots along the alignment. In balanced benching, the cut volumes equal the fill volumes and the road is often referred to as a "half-bench" road.

Bearing surface - the driving surface of the road. Road rocking is a common method of increasing the load bearing capacity of the road surface if the subgrade soils are relatively weak.

Bench - a naturally occurring bench refers to a relatively flat or low gradient portion of a hillside. A constructed bench is a step or flat area cut into a deep soil or bedrock in an attempt to create a more stable road bed.

Beneficial use-In water use law, reasonable use of water for a purpose consistent with the laws and best interest of the people of the state. Such uses include, but are not limited to, the following: instream, out of stream, and ground water uses, domestic, municipal, industrial water supply, mining, irrigation, livestock watering, fish and aquatic life, wildlife, fishing, water contact recreation, aesthetics and scenic attraction, hydropower and commercial navigation.

Berm - A curb or dike constructed to control water and prevent roadway runoff waters from discharging onto roadside slopes and/or to provide material for subsequent road maintenance.

Bottom-up road construction - road construction techniques which involve excavating a bench on the hillside and then filling and compacting fill on the bench to build up a stable roadbed at the desired elevation (as opposed to sidecasting or top-down construction).

Borrow site - locations on the landscape where sand, gravel and/or rock is excavated for use in road construction activities elsewhere in the watershed. Borrow pits and rock quarries on California wildlands may be subject to the new Surface Mining and Reclamation Act (SMARA) which requires landowners to develop site reclamation plans for many such sites (see also *rock pit)*.

Box culvert (open top) • a open-top trough-like drainage structure, usually constructed of lumber, built into and obliquely across the road surface. It acts to collect and discharge road surface runoff and, less often, ditch flow across the road. Open-top box culverts are more commonly used on ranch roads than on forest roads used for logging operations.

Buffer strip - an area or strip of land adjacent a stream containing relatively undisturbed vegetation that acts as a filter or buffer for erosion and runoff from upslope roads or other land management activities.

Center stake method - a method of curve layout, especially for switchbacks, in which a stake is used to mark the center of the curve and radial measurements are taken out from the stake to mark the curve on the ground.

Check dam (straw bale) - a temporary structure used to contain eroded soil from leaving a construction site. Straw bale check dams are often used in swales and small channels below a new road alignment to collect and store sediment eroded from the work site. Straw bale check dams quickly decompose and will usually not provide sediment storage or protection for more than a single season.

Class I watercourse - for forestry purposes, those watercourses serving as domestic water supplies, including springs, onsite and/or within 100 feet downstream of the operations area, and/or those watercourses where fish are always or seasonally present onsite, including habitat to sustain fish migration and spawning.

Class II watercourse - for forestry purposes, those watercourses where fish are always or seasonally present offsite within 1000 feet downstream, and/or watercourses which contain aquatic habitat for non-fish aquatic species. Class III watercourses that are tributary to Class I watercourses (hence within 1000 feet of a fish-bearing watercourse) are specifically excluded.

Class III watercourse - for forestry purposes, watercourses that have no aquatic life present, but still show evidence of being capable of sediment transport downstream to Class I or Class II watercourses under normal high water flow conditions after completion of timber operations.

Class IV watercourse - for forestry purposes, man-made watercourses, usually supplying downstream established domestic, agricultural, hydro-electric or other beneficial uses (see also *man-made watercourse)*.

Clearing - the act of removing the standing vegetation along a proposed road alignment. Clearing is one of the tasks of road construction, and is followed by grubbing and grading (earthmoving).

Clinometer - A pocket field instrument which measures slope steepness in degrees and percent.

Compaction - An increase in bulk density (weight per unit volume) and a decrease in soil porosity resulting from applied loads, vibration or pressure.

Control points - locations along a proposed road alignment that control the position of the road. Examples of control points include rock outcrops, the end of another road you must tie in to, a saddle on a ridge that you need the road to pass through, a favorable stream crossing location, a landslide that must be avoided, etc.

CMP - corrugated metal pipe, often used synonymously with culvert. Metal culverts are typically made from galvanized steel or aluminum.

Cross road drain - a deeply cut ditch, excavated across a road surface, which drains the road bed and inboard ditch. Cross-road drains are more substantial and deeper than conventional waterbars used to drain forest and ranch roads, and are steeper and more abrupt than rolling dips. Well constructed cross-road drains will often be deep enough to prevent vehicular access to an area and are typically installed on roads which are being closed permanently or for several years. Cross-road drains are typically constructed (excavated) using a tractor, an hydraulic excavator, or a backhoe.

Crowned - A crowned road surface is one which slopes gently away from the centerline of the road and drains to both sides of the crown. Crowning a road surface is one method of providing for surface drainage. The inside half of the road drains inward to the cutbank and ditch, while the outside half drains out across the fillslope.

Crushed rock - rock which has been run through a mechanical crusher to produce a more uniform range of particle sizes. Crushed rock is useful as a road surfacing material.

Culvert - a transverse drain, usually a metal pipe, set beneath the road surface which drains water from the inside of the road to the outside of the road. Culverts are used to drain ditches, springs and streams across the road alignment.

Curve layout - the technique or method of laying out a road curve on the ground before a road is constructed. Curves may be broad enough such that little or no layout is necessary. Switchbacks and sharp curves often require the use of surveying techniques to ensure the best, most functional design (see *center stake method).*

Cut-and-fill - a method of road construction in which a road is built by cutting into the hillside (usually using a bulldozer) and spreading the spoil materials in low spots and as sidecast along the route. "Cut-and-fill" is often a synonym for "cut-and-sidecast" (see also *balanced benching* and *top-down road construction).*

Cutslope (cutbank) - the artificial face or slope cut into soils or rock along the inside of a road.

Debris flow - A rapidly moving mass of rock fragments, soil and mud, with more than half of the particles being larger than sand size. In contrast to debris slides, debris flows are usually saturated with water.

Debris slide - A slow to rapid slide, involving downslope translation of relatively dry and predominantly unconsolidated materials, with more than half of the particles being larger than sand size.

Debris torrent - Rapid movement of a large quantity of materials (wood and sediment) down a stream channel during storms or floods. This generally occurs in smaller, steep stream channels and results in scouring of streambed.

Decking - the traveling surface (usually wood planks) of small flatcar and log stringer bridges used on forest and ranch roads. Decking is usually bolted in place and can be replaced when it is worn out.

Decommission - to remove those elements of a road that unnaturally reroute hillslope drainage or present slope stability hazards (see also *road abandonment* and *road closure).*

Decompaction - see *ripping.*

Ditch relief culvert - A drainage structure or facility which will move water from an inside road ditch to an outside area, beyond the outer edge of the road fill.

Diversion potential (DP) - a stream crossing has a diversion potential if, when the culvert plugs, the stream would back up and flow down the road rather than directly over the fill crossing and back into the natural drainage channel.

Downspout - a flume or trough attached (bolted) to a culvert outlet and used to convey water from the culvert outlet down over and beyond the road fill so as to prevent erosion. Culverts that are placed at the base of the road fill discharge directly into the natural channel or hillslope and usually do not require a downspout.

Drainage basin - see *watershed.*

Drainage blanket - a layer of permeable fill (usually gravel or coarse aggregate) several feet thick installed beneath road fill to provide subsurface drainage. Drainage blankets are typically used to drain wet soils and seeps beneath cut-and-fill and backcast constructed roads. A well drained subgrade can support up to 50% more weight than poorly drained, well graded soils.

Drainage structure - A structure installed to control, divert or to cross over water, including but not limited to culverts, bridges, ditch drains, fords, waterbreaks, outsloping and rolling dips.

Drop inlet - a vertical riser on a culvert inlet, usually of the same diameter as the culvert, and often slotted to allow water to flow into the culvert as streamflow rises around the outside. Drop inlets are often used on stream or ditch relief culverts where sediment or debris would otherwise threaten to plug a traditional horizontal inlet.

Dry seeding - a method of spreading seed on the ground surface. Dry seeding can be accomplished by drilling (actually placing seed in the ground and covering it) or by broadcasting (where seed is aerially spread over the surface of the ground).

Earthflow - A mass-movement landform and slow-to-rapid mass movement process characterized by downslope translation of soil and weathered rock over a discrete shear zone at the base, with most of the particles being smaller than sand.

Easement (right-of-way agreement) - an agreement which defines the conditions under which one party may use a road or roads owned by someone else. An easement is usually longer lived than an agreement, which may apply to a limited period of use.

Emergency road maintenance - see *storm maintenance.*

Endhauling - the removal and transportation of excavated material to prevent sidecast, and the storage of the material in a stable location where it cannot enter stream channels. Endhauling is usually accomplished using dump trucks, but on larger jobs may be performed by mobile scrapers.

Energy dissipator - A device or material used to reduce the energy of flowing water. Energy dissipators are typically used at and below culvert outlets and other drainage structures to prevent erosion.

Environmental impact - The positive or negative effect of any action upon a given area or resource.

Ephemeral streams - Streams that contain running water only sporadically, such as during and following storm events.

Equipment limitation, equipment exclusion - The terms used when the use of heavy equipment is to be limited or prohibited, respectively, for the protection of water quality, the beneficial uses of water, and/or other wildland or forest resources.

Erodible soils - soils which are relatively prone to erosion by rain drop impact and surface runoff. Granular, noncohesive soils (such as soils derived sand dunes or from decomposed granite) are known to be especially erodible.

Erosion - the dislodgement of soil particles caused by wind, raindrop impact or by water flowing across the land surface. Erosion usually refers to processes of surface erosion (rain drop erosion, rilling, gullying and ravel) and not to mass soil movement (landsliding).

Erosion control - the act of controlling on-going erosion caused by rain drop impact, rilling, gullying, ravelling and other surface processes.

Erosion hazard rating (EHR) - a calculated measure of the susceptibility of soils to erosion by raindrop impact and surface runoff. According to the California Forest Practice Rules, EHR is calculated using a defined field methodology, and the resulting rating (low, moderate, high, extreme) influence subsequent land management practices which can be employed.

Erosion prevention - preventing erosion before it has occurred. Erosion prevention is typically less expensive and more effective than erosion control.

Erosion-proof - the act of performing erosion control and erosion prevention activities which will protect a road, including its drainage structures and fills, from serious erosion during a large storm and flood.

Excess material - see *spoil.*

Fail safe - a term used to describe a stream crossing that has no diversion potential.

Fail soft - a fail safe stream crossing where the dip or change in road grade occurs over the hinge line between the fill and the natural ground surface. With the road dip or low point in this location, overflow from a plugged culvert will likely result in the least possible amount of erosion. Roads which dip deeply as they cross a stream channel have smaller fills which can be eroded when culvert plugging occurs.

Favorable ground - terrain which is favorable for road construction, usually consisting of gentle and stable slopes
and ridges.

Fifty-year flood - the magnitude of peak flow which one would expect to be equaled or exceeded, on the average, once every 50 years. This flow should be estimated by empirical relationships between precipitation, watershed characteristics and runoff, and then may be modified by direct channel cross section measurements and other evidence.

Fillslope - that part of a road fill between the outside edge of the road and the base of the fill, where it meets the natural ground surface.

Fill - the material that is placed in low areas, compacted and built up to form the roadbed or landing surface.

Filter fabric (geotextile) - a synthetic fabric manufactured and designed for use in, among others, subsurface and surface drainage applications. Filter fabric is especially useful in maintaining a separation between coarse aggregate and finer native soil particles. It comes in a number of different types (with different specifications and uses) and is used in a number of different road building settings. Manufacturer's specifications should always be consulted before using a fabric for drainage or other engineering applications.

Filter strip - see *buffer*.

Filter windrow - a row of slash and woody debris laid and pressed down along the base of a road fill or sidecast slope to contain soil eroded from the fillslope. Filter windrows are often used to contain erosion from fillslopes and sidecast areas where a road approaches and crosses a stream channel.

Fish-bearing - a stream which supports fish during some part of the year.

Flared inlet - a culvert inlet which is flared or widened to increase its capacity and reduce the chance of inlet plugging and damage. Mitred inlets, usually made by cutting a normal culvert at an angle, are also used on ditch relief culverts to decrease inlet erosion and improve culvert efficiency. Flared inlets are attached to the normal culvert inlet using a band or bolts.

Flatcar bridge - a portable bridge constructed from a railroad flatcar. Single flatcar bridges can span channels up to about 80 feet wide.

Ford (wet) - a rock, concrete or other hardened structure built on the bed of a live stream which allows vehicle passage during low flow periods.

Ford (dry) - a rock, concrete or other hardened structure built on the bed of a swale, gully or usually dry stream which allows vehicle passage during periods or low or no flow.

French drain - a buried trench, filled with coarse aggregate, which acts to drain subsurface water from a wet area and discharge it in a safe and stable location. French drains are often lined with filter fabric to keep soil from plugging the drain.

Full bench road - road construction technique in which the bench cut width is the same as the road width, and no fill is used in construction. Endhauling is needed to remove the excavated spoil material.

Full fill road - road construction technique in which no bench cut is made into the hillslope and the road prism is made entirely from imported fill. The ground surface must still be prepared (grubbed and bared) for the fill to bind to the underlying substrate.

Geomorphic - pertaining to the form or shape of the earth's surface, and to those processes that affect and shape the land's surface. Geomorphic processes include all forms of soil erosion and mass soil movement, as well as other processes.

Geotextile - *see, filter fabric.*

Grade-break - the location of a reversal in the slope (grade) of the road from climbing to falling, or from falling to climbing.

Grading - the act of excavating and moving soil along the road alignment to an established grade-line during road construction or reconstruction. Grading is one of the tasks of road construction, and is preceded by grubbing and followed by surfacing. Grading also refers to the mechanical smoothing of the road bed to maintain a free-draining, smooth traveling surface.

Groundwater - The standing body of water beneath the surface of the ground, consisting largely of surface water that has seeped down into the earth.

Grubbing - the act of scarifying the surface of the ground along a proposed road alignment prior to placing fill or sidecast on top. Grubbing is one of the tasks of road construction, and is preceded by clearing and followed by grading.

Gully (gullied) - an erosion channel formed by concentrated surface runoff which is generally larger than 1 ft^2 in cross sectional area (1' deep by 1' wide). Gullies often form where road surface or ditch runoff is directed onto unprotected slopes.

Habitat - the place where a plant or animal (including aquatic life and fish) naturally or normally lives and grows.

Headwater swale - the swale or dip in the natural topography that is upslope from a stream, at its headwaters. There may or may not be any evidence of overland or surface flow of water in the headwater swale.

Horizontal curve - The horizontal arc of a circle whose radius is that of the curve of the road.

Hydro-seeding (hydraulic seeding) - a technique for applying a slurry of seed, fertilizer and mulch by hydraulically spraying the mixture on the ground surface. Hydro-seeding is typically performed on slopes that are too steep for dry seeding.

Humboldt log crossing - see *log crossing.*

Inactive road - a road needed only infrequently, for fire control, tree thinning or other intermittent forest or ranch activities. These roads remain largely unused for most of the year, or for several years in succession, but have drainage structures intact and require regular inspection and maintenance.

Inboard ditch - the ditch on the inside of the road, usually at the foot of the cutback.

Infiltration - the movement of water through the soil surface into the soil.

Inner gorge - A stream reach bounded by steep valley walls that terminate upslope into a more gentle topography. Common in areas of rapid stream downcutting or uplift.

Insloped road - road surface that is sloped in toward the cutbank. Insloped roads usually have an inboard ditch that collects runoff from the road surface and cutbank.

Intermittent stream - Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. Intermittent streams flow in response to rainfall, and then for some period after the cessation of rainfall (being fed by groundwater discharge).

Intervisible - the ability to see from one feature to the next. Turnouts which are intervisible can be seen from one another.

Landslide - The downslope movement of a mass of earth caused by gravity. Includes but is not limited to debris slides, torrents, rock falls, debris avalanches, and creep. It does not, however, include dry ravel or surface erosion by running water. It may be caused by natural erosional processes, by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

Landing - Any place on or adjacent to a logging site (usually on a road) where logs are collected and assembled for further transport.

Landing excavation - excavation and removal of unstable or potentially unstable soil and organic debris from the outer edge or perimeter of a log landing. Landing excavations are performed as a preventive measure to guard against landsliding of unstable material into downslope stream channels.

Log crossing - a drainage structure made out of logs laid in and parallel to a stream channel and then covered with soil. Before the mid-1980's log crossings were frequently used as "permanent stream crossings" instead of culverts or bridges. Log crossings are highly susceptible to plugging and washout during storm flows. Log crossings are used today only for temporary stream crossings that are to be removed prior to the winter period.

Logging road - a road other than a public road used by trucks going to and from landings to transport logs and other forest products.

Maintained road - A road which is regularly inspected and whose cutslopes, road surface, drainage structures and fillslopes are maintained to prevent erosion and deterioration.

Man-made watercourse - a watercourse which is constructed and maintained to facilitate man's use of water. They include but are not limited to ditches and canals used for domestic, hydropower, irrigation and other beneficial uses. According to forestry regulations, man-made watercourses technically do not include road-side drainage ditches.

Mass soil movement - downslope movement of a soil mass under the force of gravity. Often used synonymously with "landslide," common types of mass soil movement include rock falls, soil creep, slumps, earthflows, debris avalanches, debris slides and debris torrents (see also *landslide)*.

Mulch - material placed or spread on the surface of the ground to protect it from raindrop, rill and gully erosion. Mulches include wood chips, rock, straw, wood fiber and a variety of other natural and synthetic materials.

Multi-benching - a road building method used on moderate or steeply sloping land in which two or more benches are excavated into the native hillslope and fill is then compacted on the benches to provide a stable road bench.

Obstacle - locations along a proposed road alignment that need to be avoided. Obstacles include rock outcrops, landslides, extremely steep slopes, unsuitable stream crossing locations, wet areas, lakes, etc.

Outsloped road - road surface that is sloped out away from the cutbank toward the road's fillslope. Outsloped roads may or may not have an inboard ditch.

Outsloping - the act of converting an insloped road to an outsloped road. Outsloping can also refer to the act of excavating the fill along the outside of the road and placing and grading it against the cutbank, thereby creating an outsloped surface where the roadbed once existed.

Partial bench - a partial bench road is one in which the road bed is part bench and part fill, somewhere between a full bench and a full fill road.

Permeable fill - see *drainage blanket.*

Peak flow (flood flow) - the highest amount of stream or river flow occurring in a year or from a single storm event.

Perennial stream - A stream that typically has running water on a year-round basis.

Permanent road - A road which is planned and constructed to be part of a permanent all-season transportation system. These roads have a surface which is suitable for hauling of forest and ranch products throughout the entire winter period and have drainage structures, if any, at watercourse crossings which will accommodate the fifty-year flood flow. Permanent roads receive regular and storm-period inspection and maintenance.

Permanent watercourse crossing - A watercourse crossing that will be constructed to accommodate the estimated fifty-year flood flow and will remain in place when timber [or ranching] operations have been completed.

Permeable fill - see *drainage blanket.*

Put-to-bed - The process of actively abandoning a road by eliminating all conceivable risks of sediment production until the road is again needed in future years. "Putting-to-bed" or road closure involves completely removing stream crossing fills and associated drainage structures and eliminating the risk of sediment production from roads and landings (see also *decommission* and *road closure).*

Ranch road - a road other than a public road used by ranch and farm vehicles in the conduct of ranching operations. Ranch roads are sometimes used for hauling forest products and thereby are also classified as, and subject to, the same regulations as logging roads.

Range finder - a hand-held field instrument used to measures distances less than about 1000 feet.

Ratio (slope) - a way of expressing slope gradient as a ratio of horizontal distance to vertical rise, such as 3:1 (3 feet horizontal for every 1 foot vertical rise of fall).

Rational formula (method) • an empirical method for estimating peak flows from a small watershed. The rational formula is often used to estimate flows and to select appropriate culvert sizes for small, ungaged stream channels crossed by a road.

Ravel (dry ravel) - soil particles dislodging and rolling down a slope under the influence of gravity. Ravel occurs most rapidly when a cohesionless soil on a steep slope dries out Ravelling is dramatically increased when frost acts on the exposed soil. Ravel on some steep, bare cutbanks can quickly fill ditches and supply sediment that is then eroded and moved to nearby ditch relief culverts or streams by concentrated ditch flow.

Reconstruction (road) - the upgrading or rebuilding of a road that is abandoned or substandard in one or more elements of its design.

Rill - an erosion channel, varying in size from a rivulet up to about 1 ft? in cross section, that typically forms where rainfall and surface runoff is concentrated on fillslopes, cutbanks and ditches. If the channel is larger than 1 ft2 in size, it is called a gully.

Rip-rap - The rock or other suitable material placed on the ground to prevent or reduce erosion.

Riparian - The banks and other adjacent terrestrial environs of lakes, watercourses, estuaries and wet areas, where transported surface and subsurface freshwater provides soil moisture to support mesic vegetation.

Ripping (road) - The process of breaking up or loosening compacted soil (e.g., skid trails, spur roads or landings) to better assure penetration of roots of young tree seedlings and to increase infiltration (see also *scarified).*

River run rock - aggregate (gravel) that is excavated from a river bed. River run rock is usually well rounded and, unless it is screened, also contains sand.

Road abandonment - in the past, road abandonment was synonymous with blocking the road and letting it grow over with vegetation. Today, proper road abandonment involves a series of proactive steps and activities which essentially erosion-proof a road alignment so that further maintenance will not be needed and significant erosion will not occur (see also *road closure, decommission).*

Road closure - or "proactive road abandonment" is a method of closing a road so that regular maintenance is no longer needed and future erosion is largely prevented. The goal of road closure is to leave the road so that little or no maintenance is required for stability while the road is unused. Road closure usually involves erosion-proofing techniques including removing stream crossing fills, removing unstable road and landing fills, installing cross road drains for permanent road surface drainage and other erosion prevention and erosion control measurers as needed. Proper road closure is not accomplished by blocking a road and walking away from it to let "nature reclaim the road" (see also *decommission, road abandonment).*

Road failure - damage to the roadbed (usually caused by a road bed slump, fill failure, stream crossing washout or major gully) which prevents vehicular passage, but does not usually mean minor cutbank or fill sloughing incidental to road settling.

Road fill excavation - excavation and removal of unstable or potentially unstable fill and/or sidecast spoil from the outer edge a road prism. Road fill excavations are performed as a preventive measure to guard against landsliding of unstable material into downslope stream channels.

Road grade - the slope of a road along its alignment.

Road maintenance - the actions taken to prevent erosion and/or the deterioration of a road, including the cutbank, the road surface, the fillslope and all drainage structures. Road maintenance activities include such tasks as grading, ditch cleaning, brushing and culvert cleaning.

Road network - the pattern of all the roads in an ownership, watershed, hillside or other defined area. The road network typically includes main trunk roads, secondary roads and spur roads.

Road reconstruction - repair or upgrading of those pre-existing roads that are to be restored or improved to make them useable for hauling forest products or for ranching operations. Reconstruction typically refers to road rebuilding required when one or more road failures have occurred (see *road failure).*

Road runoff - surface runoff that collects on and is drained from the road surface, usually as a direct response to rainfall.

Rock armor - course rock that is placed to protect a soil surface, usually from erosion caused by flowing or falling water. Rock armor is one type of material used for energy dissipation at culvert outfalls.

Rock pit - a large outcrop of bedrock that has been developed for aggregate uses, such as road surfacing material and/or larger rock armor. A borrow pit is an excavation from which material is removed for use in another location (see also *borrow site)*.

Rolling dip - shallow, rounded dip in the road where road grade reverses for a short distance and surface runoff is directed in the dip or trough to the outside or inside of the road. Rolling dips are drainage facilities constructed to remain effective while allowing passage of motor vehicles at reduced road speed.

Rotational slide - a landslide that has an accurate, concave-up failure plain, and whose movement is rotational rather than translational.

Runoff • rainfall or snowmelt which flows overland across the surface of hillslopes and along roads and trails.

Scarified (scarification) - a soil surface whose organic material is removed and whose surface is mechanically broken up or decompacted (see also *ripping)*.

Seasonal road - a road which is planned and constructed as part of a permanent transportation system where most hauling and heavy use may be discontinued during the winter period and whose use is restricted to periods when the surface is dry. Most seasonal roads are not surfaced for winter use, but have a surface adequate for hauling of forest and ranch products in the non-winter periods, and in the extended dry periods or hard frozen conditions occurring during the winter period. Seasonal roads have drainage structures at watercourse crossings which will accommodate the fifty-year flood flow.

Sediment delivery - material (usually referring to sediment) which is delivered to a stream channel. Sediment delivery often refers to the percent of material eroded from a site which actually gets delivered to a stream channel (as opposed to that which is stored on the hillslope).

Sediment yield - the quantity of soil, rock particles, organic matter, or other dissolved or suspended debris that is transported through a cross-section of stream in a given period. Technically, yield consists of dissolved load, suspended load, and bed load.

Sidecast - the excess earthen material pushed or dumped over the side of roads or landings.

Silt fence - a constructed barrier used to contain soil eroded from a construction site. The barrier is made from filter fabric stretched between fence posts placed on contour along a slope.

Sliver fill - a thin fill lying parallel to the underlying hillslope, rather than as a wedge used in normal cut and fill construction. Sliverfills cannot be compacted on slopes exceeding about 35%. As they thicken, sliver fills become more susceptible to failure. Sliver fills are only appropriate where it is impossible to dispose of the material elsewhere and where the fill is composed entirely of coarse rock. Sliverfills are "placed" and are never constructed by uncontrolled sidecasting.

Slope ratio - see *ratio.*

Slope stability - the resistance of a natural or artificial slope or other inclined surface to failure by landsliding (mass movement).

Slump - an episodic, fast to very slow mass movement process involving rotation of a block of hillslope or road along a broadly concave slip surface, often referred to as a rotational slide (see *rotational slide)*.

Soil series - a group of soils developed from a particular type of parent material having naturally developed horizons that, except for texture of the surface layer, are similar in differentiating characteristics and in arrangement of the profile.

Soil erosion - see *erosion.*

Soil texture - The relative proportion of sand, silt and clay in a soil; grouped into standard classes and subclasses in the Soil Survey Manual of the U.S. Department of Agriculture.

Soil water - water in the soil, including groundwater and water in the soil above the groundwater table.

Spoil disposal site - the location where spoil material (woody debris and excavated soils) can be placed without the threat of accelerated erosion or of initiating slope instability. Stable spoil disposal sites include the cut portion of closed roads, the inside portion of landings and turnouts, and flat or low gradient natural benches.

Spoil (spoil materials) - Material (soil and organic debris) that is not used or needed as a functional part of the road or a landing. Spoil material is generated during road construction, reconstruction and maintenance activities.

Spur road - a side road off a main trunk road or a secondary road. Most spur roads are dead-end.

Storm maintenance (emergency road maintenance) - road inspection and maintenance that is performed during periods of high rainfall and runoff when drainage structures are most likely to plug, malfunction or fail.

Stream crossing - the location where a road crosses a stream channel. Drainage structures used in stream crossings include bridges, fords, culverts and a variety of temporary crossings.

Stream crossing excavation - the excavation of the fill material that was used to build (fill) a stream crossing, specifically a culverted crossing, a log crossing or a temporary crossing. A stable stream crossing excavation must be dug down to the level of the original stream bed, with side slopes graded (excavated) back to a stable angle (usually 50% or less, depending on soil characteristics).

Subdrainage (subsurface drainage) - the flow of water beneath the surface of the ground. Along roads, specific construction techniques can be used to make sure subsurface drainage is not impeded by the road bed or road fill.

Subgrade - a thoroughly compacted portion of natural embankment material directly beneath the base or road foundation.

Surface erosion - the detachment and transport of soil particles by wind, water or gravity. Surface erosion can occur as the loss of soil in a uniform layer (sheet erosion), in many rills, gullies, or by dry ravel.

Surfacing (surface course) - the top layer of the road surface, also called the wear course. Rock aggregate and paving are two types of surfacing used to weather-proof the road for winter use.

Swale - a channel-like linear depression or low spot on a hillslope which rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface runoff under the present climatic conditions.

Switchback - the location along a road where the route turns and reverses direction, usually over a short distance.

Temporary road - a road that is to be used only during short-lived ranch or timber operations. These roads have a surface adequate for seasonal hauling use and have drainage structures, if any, adequate to carry the anticipated flow of water during the period of use. These drainage structures must be removed prior to the beginning of the winter period (see *temporary stream crossing)*.

Temporary stream crossing - a stream crossing that is to be excavated and removed, usually on a temporary road. If a temporary stream crossing is to remain in place over one winter, it should be designed to the same standards as a permanent watercourse crossing.

Through-cut - a road cut through a hillslope or, more commonly, a ridge, in which there is a cutbank on both sides of the road. Through-cuts that are more than about 2 feet deep are very difficult to drain and are prone to gullying.

Through-fill - a road which is entirely composed of fill material and which has a berm along both sides of the road, thereby intentionally containing road surface runoff on the road and directing it to a single discharge point, usually a fabricated metal berm-drain. Through-fills are typically found at sensitive stream crossings where the fill is bermed on both sides of the road.

Top-down road construction - road construction techniques which involve excavating a road bench on the hillside and sidecasting the spoil material on the slopes below. Top-down road construction techniques should only be employed on gently or moderately sloping hillslopes where sidecast material cannot fail or be eroded and transported to local stream channels.

Trash rack - a barrier built just over or just upstream from a culvert inlet to trap floating organic debris before it can plug the culvert.

Trunk road - a main, through-going road which typically forms the core of a road network that also contains secondary and spur roads.

Turnout - a planned wide spot along a single lane road that is used to allow vehicles to safely pass.

Unstable areas - areas characterized by mass movement features or unstable soils, or by some or all of the following: hummocky topography consisting of rolling bumpy ground, frequent benches, and depressions; short irregular surface drainages which begin and end on the slope; visible tension cracks and head wall scarps; irregular slopes which may be slightly concave in upper half and convex in lower half as a result of previous slope failure; evidence of impaired ground water movement resulting in local zones of saturation including sag ponds with standing water, springs, or patches of wet ground; hydrophytic (wet site) vegetation; leaning, jackstrawed or split trees; pistol-butted trees with excessive sweep in areas of hummocky topography.

Unstable soils - are indicated by the following characteristics: (1) unconsolidated, non-cohesive soils (coarser textured than loam) and colluvial debris including sands and gravels, rock fragments, or weathered granules. Such soils are usually associated with a risk of shallow-seated landslides on slopes of 65% or more, having non-cohesive soils less than 5 feet deep in an area where precipitation exceeds 4 inches in 24 hours in a 5-year recurrence interval. (2) Soils that increase and decrease in volume as moisture content changes. During dry weather, these materials become hard and rock-like exhibiting a network of polygonal shrinkage cracks and a blocky structure resulting from desiccation. Some cracks may be greater than 5 feet in depth. When wet, these materials are very sticky, dingy, shiny, and easily molded.

Vertical curve - The vertical arc of a circle whose radius is that of the road as it rises and falls (over a hill), or falls and rises (across a swale or dip) through a change in grade.

Washed out stream **crossing -** a stream crossing fill that has been partially or completely eroded and "washed" downstream. Washouts usually occur when a culvert plugs and streamflow backs up and flows over the roadbed during flood events.

Waterbar (waterbreak) - shallow ditch excavated at an angle across a road or trail to drain surface runoff. Waterbars are usually built on seasonal or temporary roads which are to receive little or no traffic during the winter period.

Watercourse - any well defined channel with distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand or gravel. Watercourse also includes man-made watercourses (see also *Class I, II, HI and IV watercourse).*

Watercourse and lake protection zone (WLPZ) - a strip of land, along both sides of a watercourse or around the circumference of a lake or spring, where additional practices (or restrictions) may be required for protection of the quality and beneficial uses of water, fish and riparian wildlife habitat, other wildland resources, and for controlling erosion.

Water quality - the chemical and biological characteristics of stream and lake water.

Watershed - the area or drainage basin contributing water, organic matter, dissolved nutrients and sediments to a stream or lake. An area bounded mostly by ridges and drained, at its outlet, by a single trunk stream.

Wetlands - areas that are inundated by surface water or ground water with a frequency sufficient to support, and under normal circumstances do or would support, a prevalence of vegetative or aquatic life that require saturated or seasonally saturated soil conditions for growth and reproduction (Executive Order 11990). Wetlands generally include, but are not limited to, swamps, marshes, bogs and similar areas.

Wheel guards - slightly elevated rails along both sides of the running surface of a flatcar bridge, designed to warn drivers and to help keep vehicles on the bridge.

Winter operations - generally refers to logging and associated forest road operations conducted during the winter operating period, from October 15 to April 15. A winter operating plan is required by the California Department of Forestry and Fire Protection for winter operations.

Winter operating period - The period between November 15 to April 1, except for purposes of installing waterbreaks and rolling dips, in which case the period is October 15 to April 1 (for forestry operations).

Winter operating plan - a functional plan developed to describe how land use operations will be conducted during the winter period. Winter operating plans usually contain detailed information on erosion control and erosion prevention actions that are to be followed to protect the site from rainfall and storm runoff.

Winterize - to perform erosion prevention and erosion control work on a road in preparation for winter rains and flood flows. Winterizing activities include waterbarring, ditch cleaning, culvert cleaning, removal of berms, resurfacing, etc.

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APPENDIX A: CULVERT SIZING PROCEDURE FOR THE 50-YEAR STORM

Introduction

Several methods have been developed for estimating the peak flood discharge that can be expected from small ungaged, wildland watersheds. These procedures are useful for determining the size (diameter) of culvert needed to install in a stream crossing that is to be constructed or reconstructed.

Determining the proper size (diameter) culvert requires: 1) estimating the volume of runoff which would occur at each stream crossing during the 50-year flood, and then 2) calculating the size of culvert which would handle that flow.

A summary of some methods, with example calculations for flood estimating is available from the California Department of Forestry and Fire Protection in an "in-house" document called *Suggested culvert sizing procedures/or the 50-year storm*. This document covers such techniques as the Rational Method, the California Nomograph Method, the Magnitude and Frequency Method, the SCS Curve Number Method and the Slope Number Method. Other techniques are also available and may have been developed for your area and climatic region. Each method has its strengths and weaknesses, and relies on field or map measurements, published climatic data and subjective evaluations of watershed conditions.

Several of the methods require precipitation intensity data which are available in several reports published by the State of California. These are available from the state and can be found in good public and college libraries. Your local CDF office may also have copies of the most recent data. Ask the Forest Practice Inspector with jurisdiction for your area.

1. Department of Water Resources, 1981 (and more recently). Rainfall depth-duration-frequency for California.

2. NOAA, 1973, Atlas 2, Precipitation frequency atlas of the western U.S., vol XI, California.

3. Department of Water Resources, 1976, Rainfall atlas for drainage design, vol. I and vol III, (out of print).

The most commonly used technique for estimating 50-year flood discharges from small watersheds in north coastal California forest land is the Rational Method. The methodology and an example is described in this appendix. However, it is recommended that two or three different methods be used in an area to compare and verify the results.Field experience can also be used as a check. Just remember, most of us have not been around for a 50-year flood and we naturally tend to underestimate the amount of water that is carried by streams during these extreme events.

Step 1: The Rational Method of Estimating Flood Discharge from Small Watersheds

This method is based on the equation:

Q=CIA

Where: Q = peak runoff at crossing (in cfs)

C = runoff coefficient (percent runoff)

I = uniform rate of rainfall intensity (inches/hour)

A = drainage area (in acres)

Advantages:

1. Frequently used and flexible enough to take into account local conditions.
2. Easy to use if local rainfall data is available.

Disadvantages:

1. Rexibility may lead to misuse, or misinterpretation of local conditions.
2. Precipitation factor "I" may be difficult to obtain in remote areas.

Information needed:

A = area of watershed (acres)

H = elevation difference between highest point in watershed and the crossing point (ft.).

L = length of channel in miles from the head of the watershed to the crossing point

I = uniform rate of rainfall intensity. Obtained from precipitation frequency-duration data for local rain gages as in example on page A5.
C = runoff coefficient from table on page Y.

Procedures:

1. Selecting "C" values:

Several different publications give a range of "C" values for the rational formula, however, the values given in the following table by Rantz (1971) appear to be the most appropriate.

Table of "C" Values		
Rural Areas		**C Value**
Sandy and gravelly soils:	cultivated	0.20
	pasture	0.15
	woodland	0.10
Loams and similar soils without impeded horizons	cultivated	0.40
	pasture	0.35
	woodland	0.30
Heavy clay soil or those with a shallow impeding horizon: shallow over bedrock:	cultivated	0.50
	pasture	0.45
	woodland	0.40

2. Selecting an "I" value:

In selecting an "I" value, two factors are considered: a) the travel time or time of concentration, T_C, for the runoff to reach the crossing, and b) the precipitation conditions for the particular watershed in question.

a. Time of concentration, T_C can be calculated using the formula:

$$T_C = \left[\frac{11.9\ L^3}{H}\right]^{0.385}$$

Where: T_C = time of concentration (in hours)

L = length of channel in miles from the head of the watershed to the crossing point

H = elevation difference between highest point in watershed and the crossing point (in feet)

b. Uniform rate of rainfall intensity.

Once the time of concentration has been determined, then that value is used to determine which rainfall duration to use (i.e., if T_C = 1 hour, then use 50-year, 1 hour precipitation duration; if T_C=4 hours, then use 50-year, 4-hour duration). Precipitation frequently, duration tables are available for precipitation stations throughout the state similar to figure 1 (DWR, 1981).

Figure 1. Short-Duration Precipitation-Depth-Duration-Frequency Data

Sample Microfiche Frame

MAXIMUM ANNUAL PRECIPITATION (IN)

STATION NO. DSN ORDER SUB	STATION NAME	ELEV	SEC	TWP	RNG	LOT	BMN	LATITUDE	LONGITUDE	COUNTY CODE
810 3649 0	GRIZZLEY FLAT	3855	15	09N	13E	6	M	38.637	120.524	09

DURATION
M=MINUTES,H=HOURS,D=DAYS,C YR=CALENDAR YEAR,W YR=WATER YEAR,F YR=FISCAL YEAR

YEAR	5M	10M	15M	30M	1H	2H	3H	6H	12H	24H	C-YR
1940	.13	.16	.19	.28	.40	.71	.99	1.28	2.16	3.07	0
1941	.21	.40	.49	.40	.70	.89	.94	1.50	2.36	3.33	50.61
1942	.20	.25	.30	.45	.57	.88	1.16	1.81	3.11	5.16	51.23
1943	.14	.23	.28	.34	.40	.89	1.02	1.82	2.95	5.32	41.21
1944	.17	.24	.29	.37	.52	.89	1.36	1.98	3.24	5.03	45.82
1945	.30	.43	.49	.79	1.08	1.17	1.27	1.96	2.78	6.39	58.10
1946	.12	.19	.21	.24	.35	.66	.91	1.43	2.35	3.72	26.32
1947	.09	.15	.22	.33	.52	.74	.85	1.28	1.78	2.22	27.00
1948	.08	.10	.11	.20	.30	.69	.71	1.25	1.97	3.21	46.52
1949	.19	.30	.31	.40	.47	.60	.80	1.31	2.61	3.30	30.57
1950	.14	.29	.36	.56	.68	.98	1.25	2.21	3.14	6.21	69.76
1951	.09	.15	.20	.32	.53	1.06	1.30	2.66	3.86	4.68	53.38
1952	.06	.10	.12	.16	.28	.52	.75	1.22	1.65	2.54	46.66
1953	.10	.20	.29	.34	.65	.77	1.01	1.61	1.75	2.41	32.42
1954	.10	.14	.19	.29	.49	.59	.81	1.02	1.49	2.67	40.55
1955	.12	.18	.24	.34	.50	.76	1.01	2.00	3.35	6.24	49.66
1956	.08	.14	.17	.25	.38	.74	.78	1.31	1.80	2.87	34.90
1957	.09	.15	.20	.39	.47	.87	1.16	1.61	2.33	2.91	43.73
1958	.11	.14	.17	.25	.40	.60	.78	1.44	2.08	2.65	49.45
1959	.10	.18	.25	.30	.37	.59	.75	1.37	1.96	2.65	28.06
1960	.22	.30	.42	.46	.53	.69	1.07	1.78	2.80	4.90	42.86
1961	.12	.15	.15	.25	.30	.49	.66	.86	1.17	1.52	24.40
1962	.09	.15	.24	.36	.65	1.15	1.56	2.61	3.81	5.63	49.89
1963	.14	.15	.26	.36	.51	.97	1.29	2.02	2.39	3.50	50.38
1964	.07	.11	.18	.30	.44	.71	.92	1.65	1.89	2.22	0

PRECIPITATION DEPTH-DURATION-FREQUENCY TABLE

STATION NO. DSN ORDER SUB	STATION NAME	ELEV	SEC	TWP	RNG	LOT	BMN	LATITUDE	LONGITUDE	COUNTY CODE
810 3649 0	GRIZZLEY FLAT	3855	15	09N	13E	6	M	38.637	120.524	09

MAXIMUM PRECIPITATION FOR INDICATED DURATION D=DAYS H=HOURS

RETURN PERIOD IN YEARS	5M	10M	15M	30M	1H	2H	3H	6H	12H	24H	C-YR
2	.12	.19	.24	.34	.47	.73	.96	1.53	2.28	3.47	42.16
5	.16	.25	.32	.45	.63	.97	1.26	2.05	3.05	4.63	53.37
10	.19	.29	.37	.52	.73	1.13	1.46	2.38	3.54	5.38	59.84
20	.22	.33	.42	.59	.82	1.25	1.65	2.68	4.00	6.08	65.51
25	.22	.34	.43	.61	.85	1.32	1.71	2.78	4.14	6.30	67.22
40	.23	.35	.44	.62	.87	1.35	1.74	2.83	4.21	6.40	70.68
50	.25	.37	.48	.67	.96	1.46	1.89	3.07	4.57	6.95	72.26
100	.27	.41	.52	.73	1.03	1.59	2.06	3.35	4.99	7.58	76.97
200	.29	.44	.56	.79	1.11	1.72	2.23	3.62	5.39	8.20	81.44
1000	.34	.52	.66	.93	1.30	2.01	2.60	4.23	6.30	9.58	91.12
10000	.41	.62	.79	1.11	1.56	2.41	3.12	5.07	7.55	11.48	103.82
PMP	.80	1.22	1.55	2.18	3.06	4.75	6.13	9.97	14.85	22.59	231.79
MEAN	.131	.199	.253	.357	.500	.776	1.003	1.631	2.429	3.694	43.206
CLOCK HR. COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CALCULATED SKEW	1.316	1.322	1.049	1.591	1.767	.415	.549	.700	.586	.507	.074
REGIONAL SKEW	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	.500
SKEW USED	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	.500
KURTOSIS	4.978	4.327	4.057	6.375	8.439	2.769	2.840	3.520	2.712	2.421	3.231
N	25	25	25	25	25	25	25	25	25	25	23
RECORD YEAR	1945	1945	1941	1945	1945	1945	1962	1951	1951	1955	1950
RECORD MAXIMUM	.300	.430	.490	.790	1.080	1.170	1.560	2.660	3.860	6.240	69.760
NORMALIZED MAX	2.964	2.648	2.342	3.191	3.505	2.025	2.150	2.283	1.975	1.890	2.335
CALC. COEF. VAR	.434	.438	.399	.380	.331	.250	.258	.276	.294	.365	.265
REGN. COEF. VAR	.341	.341	.341	.341	.341	.341	.341	.341	.341	.341	.291
USED COEF. VAR	.341	.341	.341	.341	.341	.341	.341	.341	.341	.341	.291
MEAN/A	.0030	.0046	.0059	.0083	.0116	.0180	.0232	.0377	.0562	.0855	1.0000
RP10/A	.0044	.0067	.0085	.0120	.0169	.0262	.0338	.0550	.0819	.1246	1.38[illegible]
RP25/A	.0052	.0079	.0100	.0141	.0197	.0306	.0396	.0643	.0958	.1457	1.5559
RP50/A	.0057	.0087	.0110	.0156	.0218	.0338	.0437	.0710	.1058	.1609	1.6725
RP100/A	.0062	.0095	.0120	.0170	.0238	.0369	.0476	.0775	.1156	.1755	1.7815
RP1000/A	.0079	.0120	.0153	.0214	.0300	.0466	.0602	.0979	.1458	.2218	2.1090
RP10000/A	.0096	.0143	.0182	.0257	.0360	.0559	.0722	.1176	.1748	.2658	2.4030
PMP/A	.0186	.0282	.0358	.0506	.0708	.1099	.1419	.2308	.3438	.5226	5.3450

PEARSON TYPE III DISTRIBUTION USED
PROBABLE MAXIMUM PRECIPITATION ESTIMATE BASED ON 15 STANDARD DEVIATIONS
WHERE N IS SMALL RESULTS ARE NOT DEPENDABLE

The values in Figure 1 must be converted to inches per hour as shown in the following examples:

Example 1:

T_C = 3 hours

from Figure 1, 50-year, 3-hour ppt = 1.89
1.89/3 = 0.63 inches per hour   I =0.63

Example 2:

T_C = 15 minutes

from Figure 1, 50-year, 15-minuteppt =0.48

0.48x4 = 1.92 inches per hour   I = 1.92

3. Once the "C" and "I" values are determined, apply values along with area of watershed "A" to rational equation.

Q = CIA

Example:
Digger Creek (Near Fort Bragg, California)

C = 0.30 (loam woodland soil, from Table 1, page A3)

$$\mathbf{T_C} = \left[\frac{11.9(1.8 \text{ mi.})^3}{200}\right]^{0.385}$$ where: L = 1.8 mi., A =200 ft.

= 0.67 or 40 min. from the Intensity Duration Frequency table (see example above and Figure 1, page A4)

I = 1.4in./hr.

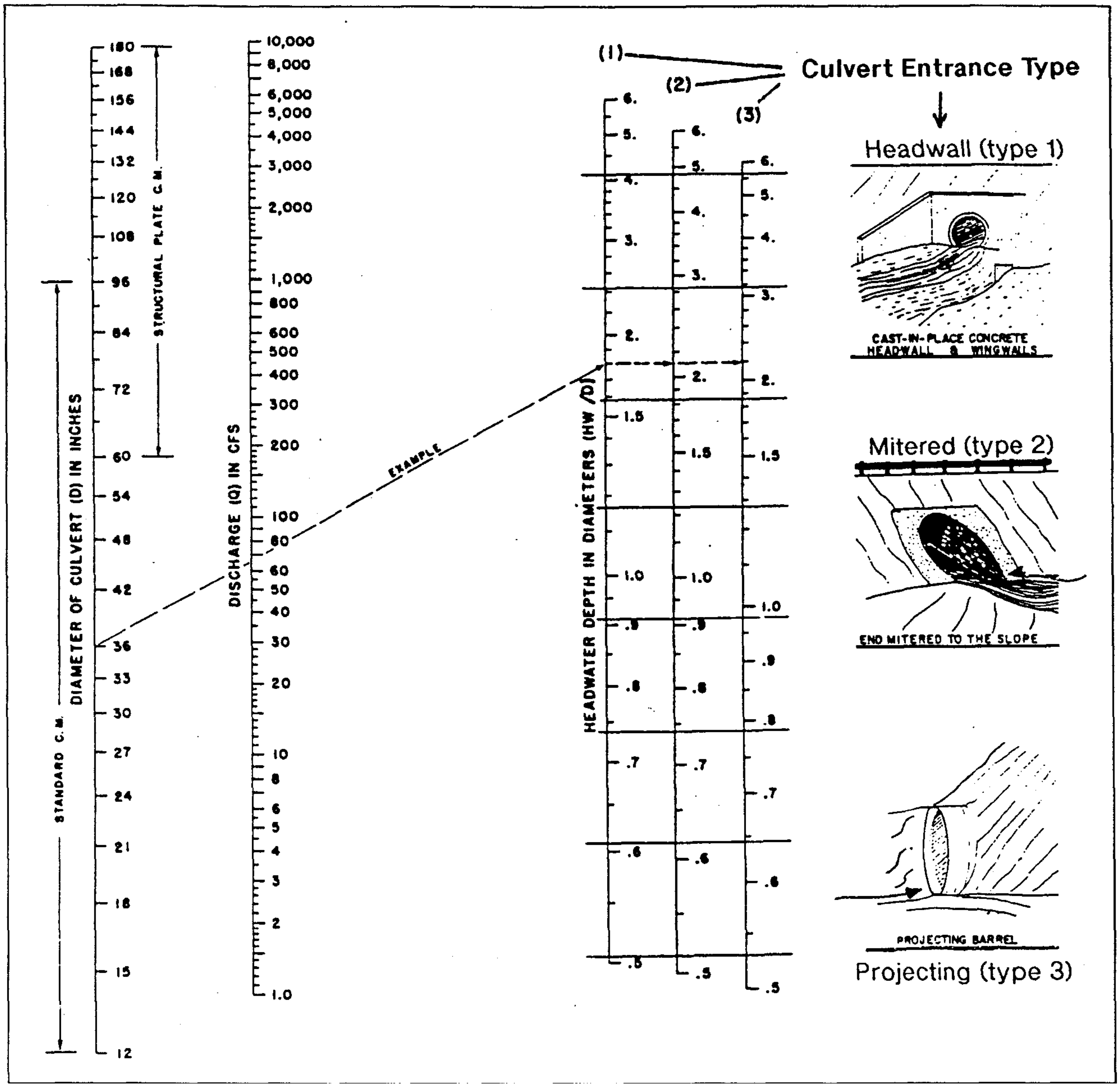
A = 536 acres

Q = CIA

Q = 0.30 x 1.4 x 536

= 225 cfs

Step 2: Using the Culvert Capacity Nomograph to determine needed culvert size



1. Determine the "entrance type" from the sketches above.
2. Calculate the expected "Headwater Depth" in **diameters** from field measurements (e.g., a 36 inch culvert whose bottom will be 8 feet below the lowest point on the road grade over the crossing has a headwater depth of 8 feet, or 2.7 culvert-diameters (8ft./3 ft. = 2.7).
3. Place a straight edge connecting the Headwater Diameter scale (right side of nomograph) through the calculated 50-year flood discharge (from the Rational Method, in this example).
4. Read off the needed culvert diameter on the left scale of the nomograph.
5. In the example, the Headwater Depth for a Type 1 entrance (1.8), Type 2 entrance (2.1) or a Type 3 entrance (2.2) culvert to be installed on a small stream with a calculated 50-year flood discharge of 66 cubic feet per second would require a 36-inch diameter culvert.

APPENDIX B: STREAMBED ALTERATION AGREEMENT

Notification No. ______________ THP No. ______________

AGREEMENT REGARDING PROPOSED STREAM OR LAKE ALTERATION

THIS AGREEMENT, entered into between the State of California, Department of Fish and Game, hereinafter called the Department, and ______________________________
of ______________, State of ____________________, hereinafter called the operator, is as follows:

WHEREAS, pursuant to Division 2, Chapter 6 of California Fish and Game Code, the operator, on the ______ day of __________ 19______, notified the Department that he intends to substantially divert or obstruct the natural flow of, or substantially change the bed channel, or bank of, or use material from the streambed of, the following water: ______________________________, in the County of ______________, State of California, S________ T________ R________.

WHEREAS, the Department (represented by ______________________________ has made an inspection of subject area on the __________ day of ______________________________, 19 ____, and) has determined that such operations may substantially adversely affect existing fish and wildlife resources including: ______________________________
____
______________________________.

THEREFORE, the Department hereby proposes measures to protect fish and wildlife during the operator's work. The operator hereby agrees to accept the following recommendations as part of his work: Numbers ______________________________ from the list of recommendations on the back of this page and the following special recommendations:

1. All work in or near the stream or lake shall be confined to the period ______________________________
____
____
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____

The operator, as designated by the signature on this agreement, shall be responsible for the execution of all elements of this agreement. A copy of this agreement must be provided to contractors and subcontractors and must be in their possession at the work site.

If the operator's work changes from that stated in the notification specified above, this agreement is no longer valid and a new notification shall be submitted to the Department of Fish and Game. Failure to comply with the provisions of this agreement and with other pertinent Code Sections, including but not limited to Fish and Game Code Sections 5650, 5652 and 5948, may result in prosecution.

Nothing in this agreement authorizes the operator to trespass on any land or property, nor does it relieve the operator of responsibility for compliance with applicable federal, state, or local laws or ordinances.

THIS AGREEMENT IS NOT INTENDED AS AN APPROVAL OF A PROJECT OR OF SPECIFIC PROJECT FEATURES BY THE DEPARTMENT OF FISH AND GAME. INDEPENDENT REVIEW AND RECOMMENDATIONS WILL BE PROVIDED BY THE DEPARTMENT AS APPROPRIATE ON THOSE PROJECTS WHERE LOCAL, STATE, OR FEDERAL PERMITS OR OTHER ENVIRONMENTAL REPORTS ARE REQUIRED.

This agreement becomes effective on ______________________________

Operator ______________________	______________________ Department Representative
Title ______________________	Title ______________________
Organization ______________________	Department of Fish and Game, State of California
Date ______________________	Date ______________________

The department has 30 days from date of receipt of a completed application in which to make its recommendations. This time period does not begin until the department receives the appropriate fee (see attached fee schedule).

T.H.P. No. ____________

Notification No. ____________ Received ____________

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME

NOTIFICATION OF REMOVAL OF MATERIALS AND/OR ALTERATION OF LAKE, RIVER, OR STREAMBED BOTTOM, OR MARGIN

A. APPLICANT Pursuant to Sections 1601–1607 of the California Fish and Game Code

I. ____________ (Name of Applicant) of ____________ (Mailing Address),

Representing ____________ (Name and address of Individual, Agency, Company, etc. owning property or doing work.)

Hereby notify the California Department of Fish and Game of operations to be carried out by or for me

from ____________ (Starting Date) to ____________ (Ending Date) on or affecting

____________ (Name of Stream, River, or Lake) of ____________ County, tributary to ____________ (Major Water Body)

Located ____________ (Distance and Direction to Landmarks)

Section ____________ Township ____________ Range ____________

USGS Map ____________ Co. Assessor's Parcel No. ____________

Property owners name and address (if different from applicant) ____________

____

____________ (Name of Person to Be Contacted at Site During Operations) is responsible for operations at the site.

He/she can be reached at ____________ (Mailing Address) ____________ (Telephone)

B. Description of operation 1. The nature of said operations will be as follows:
Check all squares which apply.

- ☐ Soil, sand, gravel, and/or boulder removal or displacement
- ☐ Water diversion or impoundment
- ☐ Mining—other than aggregate removal
- ☐ Road or bridge construction
- ☐ Levee or channel construction
- ☐ Timber harvesting or any related activity required for harvesting timber
- ☐ Temporary, recreational or irrigation dam
- ☐ Fill or spoil in bed, bank, or channel
- ☐ Other—Describe below

2. Type of material removed, displaced or added ☐ Soil ☐ Sand ☐ Gravel ☐ Boulders
Volume ____________
3. Equipment to be used in the described site ____________
4. Use of water (i.e., domestic, irrigation, gravel washing, etc.) ____________ Quantity ____________
5. Describe type and density of vegetation to be affected, and estimate area involved.
____
6. What actions are proposed to protect fish and wildlife resources and/or mitigate for project impacts? ____________
____

7a. Does project have a local or state lead agency or require other permits? ☐ Yes ☐ No

7b. If 7a answer is yes, please attach or identify any available environmental document.

7c. For state-designated wild and scenic rivers, a determination of the project's consistency with the California Wild and Scenic Rivers Act must be made by the Secretary for Resources. Until the Secretary determines the project is consistent with the Act, the Department cannot issue a valid agreement. A tentative agreement will be issued, conditioned upon a finding of consistency by the Resources Secretary.

7d. THIS AGREEMENT IS NOT INTENDED AS AN APPROVAL OF A PROJECT OR OF SPECIFIC PROJECT FEATURES BY THE DEPARTMENT OF FISH AND GAME. INDEPENDENT REVIEW AND RECOMMENDATIONS WILL BE PROVIDED BY THE DEPARTMENT AS APPROPRIATE ON THOSE PROJECTS WHERE LOCAL, STATE, OR FEDERAL PERMITS OR OTHER ENVIRONMENTAL REPORTS ARE REQUIRED.

8. Briefly describe proposed construction methods. Attach diagram or sketch of the location of your operation to clearly indicate the stream or other water and access and distance from named public road. Indicate locked gates with an "X". Show existing features with a solid line (————) and proposed features with a broken line (- - - - - - -). Show compass direction. Attach larger scale map if necessary.

NO CARBON NEEDED
FG2023 (REV. 11/87)

____________ Signature of Applicant ____________ Date

37 83409

DEPARTMENT OF FISH AND GAME
Notification of Proposed Removal of Materials and/or
Alteration of Lake, River, or Streambed Bottom or Bank
(Pursuant to Sections 1603-1606, Fish and Game Code)

The following information that accompanies the Timber Harvesting Plan is not a part of the Timber Harvesting Plan to be enforced by the Department of Forestry. Such information is given only for convenience in providing notice to the Department of Fish and Game as required by Sections 1603 and 1606 of the Fish and Game Code of proposed timber operations that will substantially divert, obstruct, or change the flow or bed of any river, stream, or lake. If the proposed timber operations in the Timber Harvesting Plan area do not involve any such disturbance to rivers, streams, or lakes, this attachment should be left blank. If at a later date it is decided that operations will involve disturbances to rivers, streams, or lakes, a separate notification should be submitted to the Department of Fish and Game at that time.

Attach a sketch of the location of the proposed operation which clearly indicates the stream or other water, and access from a named public road. Locked gates and the compass direction shall be indicated. Please indicate the location of all proposed stream crossings, fills, dikes, excavations, log landings (near streams), streambed vegetation removal, channel changes, impoundments, diversions or other significant alterations to rivers, streams, or lakes. (This may require a larger scale map.)

Date____________________ THP Number____________________
(leave blank)

Please Fill In Applicable Blanks

(1) Streambed Excavations:

(a) Approximate volume of material to be removed from streambed: ______cu. yds.*

(b) Type of material removed (rock, gravel, sand, soil, etc.):____________

____

(c) Equipment to be used (bulldozer, backhoe, dragline, bucket dredge, etc.):

____

(d) Type, density and area of vegetation to be removed:________________

____

(2) Stream Crossings, Channel Changes, Landings or Other Fills Near Streams:

(a) Purpose of activity (culvert, bridge, skid crossing, ford, landing, dike, etc.). Please indicate which crossings are permanent:

____

(b) Approximate volume and type of material to be deposited in streambed:

____

(c) Type of equipment to be used:____________________________

* Excavations are generally not permitted within the flowline of a stream unless the water is diked off from the excavation.

Attachment to Form FM-63 (12/76)

(d) How long will equipment be used in flowing water to install crossings or isolate work area from flowing water? (Prolonged work in flowing water is usually not permitted): ______________________________

____

(e) Type, density and area of vegetation to be removed: ______________________

____

(3) Impoundments and Diversions:

(a) Volume and type of material to be deposited in streambed: ______________

____

(b) Quantity of water to be used: ______________________________

(c) Intended water use (i.e., fire and dust control, etc.): ______________

____

(d) Describe the period of time in which operations will be carried out: _____

____

(4) Name and/or Legal Description of Area (include names of USGS Quadrangle Map).

____

____

(5) Work in or near the stream or lake is to be performed during the period ______

______________________ to ______________________

(6) If an onsite inspection, in your opinion, is not possible because of weather or other circumstances within the next 30 days, you may enter into a mutual agreement to extend the period for inspection an additional 30 days. If you agree to an additional 30 days, indicate a new notification date which will start the 30 day period.

______________________ Notification Date

______________________ Signature

If the proposed activity is amended to change any of the above, or if it is not completed within the agreed upon time period, the Department shall be notified.

Please fill in the following:

______________________ Name (Print or Type)

______________________ Signature

______________________ Address

______________ City

________ State

________ Zip Code

( ) - ______________________ Telephone No.

APPENDIX C: FORESTRY RULES FOR ROAD CONSTRUCTION AND MAINTENANCE

Article 12. Logging Roads and Landings

§§ 923, 943, 963. Logging Roads and Landings. [All Districts]

All logging roads and landings in the logging area shall be planned, located, constructed, reconstructed, used, and maintained in a manner which: is consistent with long-term enhancement and maintenance of the forest resource; best accommodates appropriate yarding systems, and economic feasibility; minimizes damage to soil resources and fish and wildlife habitat; and prevents degradation of the quality and beneficial uses of water. The provisions of this article shall be applied in a manner which complies with this standard.

Factors that shall be considered when selecting feasible alternatives (see 14 CCR 897 and 898) shall include, but are not limited to, the following:

(a) Use of existing roads whenever feasible.

(b) Use of systematic road layout patterns **to** minimize total mileage.

(c) Planned to fit topography to minimize disturbance to the natural features of the site.

(d) Avoidance of routes near the bottoms of steep and narrow canyons, through marshes and wet meadows, on unstable areas, and near watercourses or near existing nesting sites of threatened or endangered bird species.

(e) Minimization of the number of watercourse crossings.

(f) Location of roads on natural benches, flatter slopes and areas of stable soils to minimize effects on watercourses.

(g) Use of logging systems which will reduce excavation or placement of fills on unstable areas.

§§923.1,943.1,963.1. Planning for Roads and Landings. [All Districts]

The following standards for logging roads and landings shall be adhered to:

(a) All logging roads shall be located and classified on the THP map as permanent, seasonal, or temporary. Road failures on existing roads which will be reconstructed shall also be located on the THP map. In addition to the requirements of 14 CCR 1034(v), the probable location of those landings which require substantial excavation or which exceed one quarter acre in size, shall be shown on the THP map.

(b) New logging roads shall be planned in accordance with their classification and maintenance requirements.

(c) Logging roads and landings shall be planned and located, when feasible, to avoid unstable areas. The Director shall approve an exception if those areas are unavoidable, and site-specific measures to minimize slope instability due to construction are described and justified in the THP.

(d) Where roads and landings will be located across 100 feet or more of lineal distance on any slopes over 65% or on slopes over 50% which are within 100 feet of the boundary of a WLPZ, measures to minimize movement of soil and the discharge of concentrated surface runoff shall be incorporated in the THP. The Director may waive inclusion of such measures where the RPF can show that slope depressions, drainage ways, and other natural retention and detention features are sufficient to control overland transport of eroded material. The Director may require end-hauling of material from areas within 100 feet of the boundary of a WLPZ to a stable location if end hauling is feasible and is necessary to protect water quality. The Director shall require maintenance provisions in the THP for drainage structures and facilities provided that such maintenance is feasible and necessary to keep roadbeds and fills stable.

(e) New logging roads shall not exceed a grade of 15% except that pitches of up to 20% shall be allowed not to exceed 500 continuous feet (152.4m). These percentages and distances may be exceeded only where it can be explained and justified in the THP that there is no other feasible access for harvesting of timber or where in the Northern or Southern Districts use of a gradient in excess of 20% will serve to reduce soil disturbance.

(f) Roads and landings shall be planned so that an adequate number of drainage facilities and structures are installed to minimize erosions on roadbeds, landing surfaces, sidecast and fills.

(g) Unless exceptions are explained and justified in the THP, general planning requirements for roads shall include:

> (1) Logging roads shall be planned to a single-lane width compatible with the largest type of equipment used in the harvesting operation with turnouts at reasonable intervals.
>
> (2) Roads shall be planned to achieve as close a balance between cut volume and fill volume as is feasible.
>
> (3) When roads must be planned so that they are insloped and ditched on the uphill side, drainage shall be provided by use of an adequate number of ditch drains.

(h) Road construction shall be planned to stay out of Watercourse and Lake Protection Zones. When it is a better alternative for protection of water quality or other forest resources, or when such roads are the only feasible access to timber, exceptions may be explained and justified in the THP and shall be agreed to by the Director if they meet the requirements of this subsection.

(i) [Coast] The location of all logging roads to be constructed shall be flagged or otherwise identified on the ground before submission of a TUP or major amendment. Exceptions may be explained and justified in the THP and agreed to by the Director if flagging is unnecessary as a substantial aid to examining (1) compatibility between road location and yarding and silvicultural systems, or (2) possible significant adverse effects of road location on water quality, soil productivity, wildlife habitat, or other special features of the area.

(i) **[Northern, Southern]** All logging roads shall be flagged or otherwise identified on the ground before submission of a THP or major amendment, except for temporary roads less than 600 feet in length that would meet the requirements for a minor deviation (see 14 CCR 1036,1039,1040) if they were submitted as such. Exceptions may be explained and justified in the THP and agreed to by the Director if flagging or other identification is unnecessary as a substantial aid to examining (1) compatibility between road location and yarding and silvicultural systems or (2) possible significant adverse effects of road location on water quality, soil productivity, wildlife habitat, or other special features of the area.

§§ 923.2, 943.2, 963.2. Road Construction. [All Districts]

Logging roads shall be constructed or reconstructed in accordance with the following requirements or as proposed by the RPF, justified in the THP, and found by the Director to be in conformance with the requirements of this Article.

(a) Logging roads shall be constructed in accordance with the approved THP. If a change in designation of road classification is subsequently made, the change shall be reported in accordance with 14 CCR 1039 or 1040, as appropriate.

(b) Where a road section which is greater than 100 feet in length crosses slopes greater than 65 percent, placement of fill is prohibited and placement of sidecast shall be minimized to the degree feasible. The director may approve an exception where site specific measures to minimize slope instability, soil erosion, and discharge of concentrated surface runoff are described and justified in the THP.

(c) On slopes greater than 50 percent, where the length of road section is greater than 100 feet, and the road is more than 15 feet wide (as measured from the base of the cut slope to the outside of the berm or shoulder of the road) and the fill is more than 4 feet in vertical height at the road shoulder for the entire 100 feet the road shall be constructed on a bench that is excavated at the proposed toe of the compacted fill and the fill shall be compacted. The Director may approve exception to this requirement where on a site-specific basis a Registered Professional Forester has described and justified an alternative practice that will provide equal protection to water quality and prevention of soil erosion.

(d) [Coast] Fills, including through fills across watercourses shall be constructed in a manner to minimize erosion of fill slopes using techniques such as insloping through-fill approaches, waterbars, berms, rock armoring of fill slopes, or other suitable methods.

(d) **[Northern, Southern]** Roads shall be constructed so no break in grade, other than that needed to drain the fill, shall occur on through fill; breaks in grade shall be above or below the through fill, as appropriate. Where conditions do not allow the grade to break as required, through fills must be adequately protected by additional drainage structures or facilities.

(e) Through fills shall be constructed in approximately one foot lifts.

(f) On slopes greater than 35 percent, the organic layer of the soil shall be substantially disturbed or removed prior to fill placement. The RPF may propose an exception in the THP and the Director may approve the exception where it is justified that the fill will be stabilized.

(g) Excess material from road construction and reconstruction shall be deposited and stabilized in a manner or in areas where downstream beneficial uses of water will not be adversely affected.

(h) Drainage structures and facilities shall be of sufficient size, number and location to carry runoff water off of roadbeds, landings and fill slopes. Drainage structures or facilities shall be installed so as to minimize erosion, to ensure proper functioning, and to maintain or restore the natural drainage pattern. Permanent watercourse crossings and associated fills and approaches shall be constructed where feasible to prevent diversion of stream overflow down the road and to minimize fill erosion should the drainage structure become plugged.

(i) Where there is evidence that soil and other debris is likely to significantly reduce culvert capacity below design flow, oversize culverts, trash racks, or similar devices shall be installed in a manner that minimizes culvert blockage.

(j) Waste organic material, such as uprooted stumps, cull logs, accumulations of limbs and branches, and unmerchantable trees, shall not be buried in road fills. Wood debris or cull logs and chunks may be placed and stabilized at the toe of fills to restrain excavated soil from moving downslope.

(k) Logging roads shall be constructed without overhanging banks.

(1) Any tree over 12 inches (30.5 cm) d.b.h. with more than 25 percent of the root surface exposed by road construction, shall be felled concurrently with the timber operations.

(m) Sidecast or fill material extending more than 20 feet (6.1 m) in slope distance from the outside edge of the roadbed which has access to a watercourse or lake which is protected by a WLPZ shall be seeded, planted, mulched, removed, or treated as specified in the THP, to adequately reduce soil erosion.

(n) All culverts at watercourse crossings in which water is flowing at the time of installation shall be installed with their necessary protective structures concurrently with the fill, construction and reconstruction of logging roads. Other permanent drainage structures shall be installed no later than October 15. For construction and reconstruction of roads after October 15, drainage structures shall be installed concurrently with the activity.

(o) Drainage structures and drainage facilities on logging roads shall not discharge on credible fill or other credible material unless suitable energy dissipators are used. Energy dissipators suitable for use with waterbreaks are described in 14 CCR 914.6(f) [934.6(f), 954.6(f)].

(p) Where roads do not have permanent and adequate drainage, the specifications of Section 914.6 [934.6, 954.6] shall be followed.

(q) Drainage facilities shall be in place and functional by October 15. An exception is that waterbreaks do not need to be constructed on roads in use after October 15 provided that all such waterbreaks are installed prior to the start of rain that generates overland flow.

(r) No road construction shall occur under saturated soil conditions, except that construction may occur on isolated wet spots arising from localized ground water such as springs, provided measures are taken to prevent material from significantly damaging water quality.

(s) Road construction not completed before October 15 shall be drained by outsloping, waterbreaks and/or cross-draining before the beginning of the winter period. If road construction does take place after October 15, roads shall be adequately drained concurrent with construction operations.

(t) Roads to be used for log hauling during the winter period shall be, where necessary, surfaced with rock in depth and quantity sufficient to maintain a stable road surface throughout the period of use. Exceptions may be proposed by the RPF, justified in the THP, and found by the Director to be in conformance with the requirements of this subsection.

(u) Slash and other debris from road construction shall not be bunched against residual trees which are required for silvicultural or wildlife purposes, nor shall it be placed in locations where it could be discharged into Class I or n watercourses.

(v) Road construction activities in the WLPZ, except for stream crossings or as specified in the TUP, shall be prohibited.

§§ 923.3, 943.3, 963.3. Watercourse Crossings. [All Districts]

Watercourse crossing drainage structures on logging roads shall be planned, constructed, and maintained or removed, according to the following standards. Exceptions may be provided through application of Fish and Game Code Sections 1601 and 1603 and shall be included in the THP.

(a) The location of all new permanent watercourse crossing drainage structures and temporary crossings located within the WLPZ shall be shown on the THP map. If the structure is a culvert intended for permanent use, the minimum diameter of the culvert shall be specified in the plan. Extra culverts beyond those shown in the THP map may be installed as necessary.

(b) The number of crossings shall be kept to a feasible minimum.

(c) Drainage structures on watercourses that support fish shall allow for unrestricted passage of fish.

(d) When watercourse crossings, other drainage structures, and associated fills are removed the following standards shall apply:

(1) Fills shall be excavated to form a channel which is as close as feasible to the natural watercourse grade and orientation and is wider than the natural channel.

(2) The excavated material and any resulting cut bank shall be sloped back from the channel and stabilized to prevent slumping and to minimize soil erosion. Where needed, this material shall be stabilized by seeding, mulching, rock armoring, or other suitable treatment.

(e) Permanent watercourse crossings and associated fills and approaches shall be constructed or maintained to prevent diversion of stream overflow down the road and to minimize fill erosion should the drainage structure become obstructed. The RPF may propose an exception where explained in the THP and shown on the THP map and justified how the protection provided by the proposed practice is at least equal to the protection provided by the standard rule.

§§ 923.4, 943.4, 963.4. Road Maintenance. [All Districts]

Logging roads, landings, and associated drainage structures used in a timber operation shall be maintained in a manner which minimizes concentration of runoff, soil erosion, and slope instability and which prevents degradation of the quality and beneficial uses of water during timber operations and throughout the prescribed maintenance period. In addition those roads which are used in connection with stocking activities shall be maintained throughout their use even if this is beyond the prescribed maintenance period.

(a) The prescribed maintenance period for erosion controls on permanent and seasonal roads and associated landings and drainage structures which are not abandoned in accordance with 14 CCR 923.8 [943.8,963.8] shall be at least one year. The Director may prescribe a maintenance period extending up to three years in accordance with 14 CCR 1050.

(b) Upon completion of timber operations, temporary roads and associated landings shall be abandoned in accordance with 14 CCR 923.8 [943.8,963.8].

(c) Waterbreaks shall be maintained as specified in 14 **CCR** 914.6 [934.6,954.6].

(d) Unless partially blocked to create a temporary water source, watercourse crossing facilities and drainage structures, where feasible, shall be kept open to the unrestricted passage of water. Where needed, trash racks or similar devices shall be installed at culvert inlets m a manner which minimizes culvert blockage. Temporary blockages shall be removed by November 15.

(e) Before the beginning of the winter period, all roadside berms shall be removed from logging roads or breached, except where needed to facilitate erosion control.

(f) Drainage structures, if not adequate to carry water from the fifty-year flood level, shall be removed in accordance with 14 CCR 923.3(d) [943.3(d), 963.3(d)] by the first day of the winter period, before the flow of water exceeds their capacity if operations are conducted during the winter period, or by the end of timber operations whichever occurs first. Properly functioning drainage structures on roads that existed before timber operations need not be removed. The RPF may utilize an alternative practice, such as breaching of fill, if the practice is approved by the Director as providing greater or equal protection to water quality as removal of the drainage structure.

(g) Temporary roads shall be blocked or otherwise closed to normal vehicular traffic before the winter period.

(h) During timber operations, road running surfaces in the logging area shall be treated for stabilization (rocked, watered, chemically treated, asphalted or oiled) where necessary to prevent excessive loss or road surface materials.

(i) Soil stabilization treatments on road or landing cuts, fills, or sidecast shall be installed or renewed, when such treatment could minimize surface erosion which threatens the beneficial uses of water.

(j) Drainage ditches shall be maintained to allow free flow of water and minimize soil erosion.

(k) Action shall be taken to prevent failures of cut, fill, or sidecast slopes from discharging materials into watercourses or lakes in quantities deleterious to the quality or beneficial uses of water.

(1) Each drainage structure and any appurtenant trash rack shall be maintained and repaired as needed to prevent blockage and to provide adequate carrying capacity. Where not present, new trash racks shall be installed if there is evidence that woody debris is likely to significantly reduce flow through a drainage structure.

(m) Inlet and outlet structures, additional drainage structures (including ditch drains), and other features to provide adequate capacity and to minimize erosion of road and landing fill and sidecast to minimize soil erosion and to minimize slope instability shall be repaired, replaced, or installed wherever such maintenance is needed to protect the quality and beneficial uses of water.

(n) Permanent watercourse crossings and associated approaches shall be maintained to prevent diversion of stream overflow down the road should the drainage structure become plugged. Corrective action shall be taken before the completion of timber operations or the drainage structure shall be removed in accordance with 14 CCR Section 923.3 (d) [943.3(d), 963.3(d)].

(o) Except for emergencies and maintenance needed to protect water quality, use of heavy equipment for maintenance is prohibited during wet weather where roads or landings are within a WLPZ.

(p) The Director may approve an exception to a requirement set forth in subsections (b) through (o) above when such exceptions are explained and justified in the THP and the exception would provide for the protection of the beneficial uses of water or control erosion to a standard at least equal to that which would result from the application of the standard rule.

§§ 923.5, 943.5, 963.5. Landing Construction. [All Districts]

Landings shall be constructed according to the following standards:

(a) On slopes greater than 65 percent, no fill shall be placed and sidecast shall be minimized to the degree feasible. The director may approve an exception if, site specific measures to minimize slope instability, soil erosion, and discharge of concentrated surface runoff are described and justified in the THP.

(b) On slopes greater than 50 percent, fills greater than 4 feet in vertical height at the outside shoulder of the landing shall be: 1) constructed on a bench that is excavated at the proposed toe of the fill and is wide enough to compact the first lift, and 2) compacted in approximately 1 foot lift from the toe to the finished grade. The RPF shall flag the location of this bench or shall provide a description of the bench location (narrative or drawing) in the THP for fills meeting the above criteria, where the length of landing section is greater than 100 feet. The RPF may propose an exception in the THP and the Director may approve the exception where it is justified that the landing will be stabilized.

(c) Waste organic material, such as uprooted stumps cull logs, accumulations of limbs and branches, or unmerchantable trees, shall not be buried in landing fills. Wood debris or cull logs and chunks may be placed and stabilized at the toe of landing fills to restrain excavated soil from moving downslope.

(d) Constructed landings shall be the minimum in width, size, and number consistent with the yarding and loading system to be used. Landings shall be no larger than one-half acre (0.202 ha) unless explained and justified in the THP.

(e) No landing construction shall occur under saturated soil condition.

(f) The following specifications shall be met upon completion of timber operations for the year or prior to October 15, whichever occurs first:

(1) Overhanging or unstable concentrations of slash, woody debris and soil along the downslope edge or face of the landings shall be removed or stabilized when they are located on slopes over 65 percent or on slopes over 50 percent within 100 feet of a WLPZ.

(2) Any obstructed ditches and culverts shall be cleaned.

(3) Landings shall be sloped or ditched to prevent water from accumulating on the landings. Discharge points shall be located and designed to reduce erosion.

(4) Sidecast or fill material extending more than 20 feet in slope distance from the outside edge of the landing and which has access to a watercourse or lake shall be seeded, planted, mulched, removed or treated as specified in the THP to adequately reduce soil erosion.

(5) Sidecast or fill material extending across a watercourse shall be removed in accordance with standards for watercourse crossing removal set forth in 14 CCR 923.3 (d).

(g) On slopes greater than 35 percent, the organic layer of the soil shall substantially removed prior to fill placement

(h) When landings are constructed after October 15 they shall be adequately drained concurrent with construction operations and shall meet the requirements of (f)(l) through (f)(4) of this subsection upon completion of operations at that landing.

(j) The RPF may propose and the Director may approve waiver of requirements in (f)(l) through (f)(4) of this subsection if the Director finds they are not necessary to minimize erosion or prevent damage to downstream beneficial uses. The Director may also approve an exception to the October 15th date for treatment of slash and debris, including the practice of burning.

§§ 923.6, 943.6, 963.6. Conduct of Operations on Roads and Landings [All Districts]

Routine use and maintenance of roads and landings shall not take place when, due to general wet conditions, equipment cannot operate under its own power. Operations may take place when roads and landings are generally firm and easily passable or during hard frozen conditions. Isolated wet spots on these roads or landings shall be rocked or otherwise treated to permit passage. However, operations and maintenance shall not occur when sediment discharged from landings or roads will reach watercourses or lakes in amounts deleterious to the quality and beneficial uses of water.

This section shall not be construed to prohibit activities undertaken to protect the road or to reduce erosion.

APPENDIX D: STICK METHOD OF CURVE LAYOUT

Horizontal Curve Layout

Two simple procedures are described. The first, the center stake method, has been described in the text of the Handbook. The second, a stick procedure, is described below. The center stake method is limited to gentle terrain and good visibility while the latter is more suitable to difficult sites.

Stick Method

Simple curves may be staked on the ground with a stick and a tape. Using a 25 or 50 foot staking distance, consult Table D-l for the proper stick length to set the radius shown. Figure D-l shows the process.

Adjustments needed for Topography and Grade

The curve layout description assumes that the area is flat. Seldom is this the case. Measurements of length then need adjustment to compensate for slopes.

When the distance being measured is short, the tape can be held level. For longer lengths, measure the distance by segments-each held level. Where the distance is longer than convenient for the leveling method, adjust the measured slope's length by using Table 11 (see Chapter ffl).

Grade may be carried around the curve by running a line with the desired slope for the distance of the curve. This will often be away from the center line of the road due to the topography. If this occurs, run a level line to the point of tangency (PT), where the curve ends (see Figure D-2).

Table D-l. Stick length for curve radius by stake distance (ft)		
Curve Radius Feet	Stake Distance	
	25 feet	50 feet
50	6.7[1]	
60	5.5	26.8
80	4.1	17.6
100	3.2	13.4
150	2.1	8.6
200	1.6	6.4
250	1.3	5.1
300	1.1	4.2
350	0.9	3.6
400	0.8	3.1
600	0.5	2.1
800	0.4	1.6
1000	0.3	1.3

[1] *Convert tenths offeet to inches by multiplying 12 x decimal shown in table. For example: 6.7 ft.; 0.7 x 12 = 8.4 or 8; 6ft. 8 inches.*

Switchbacks

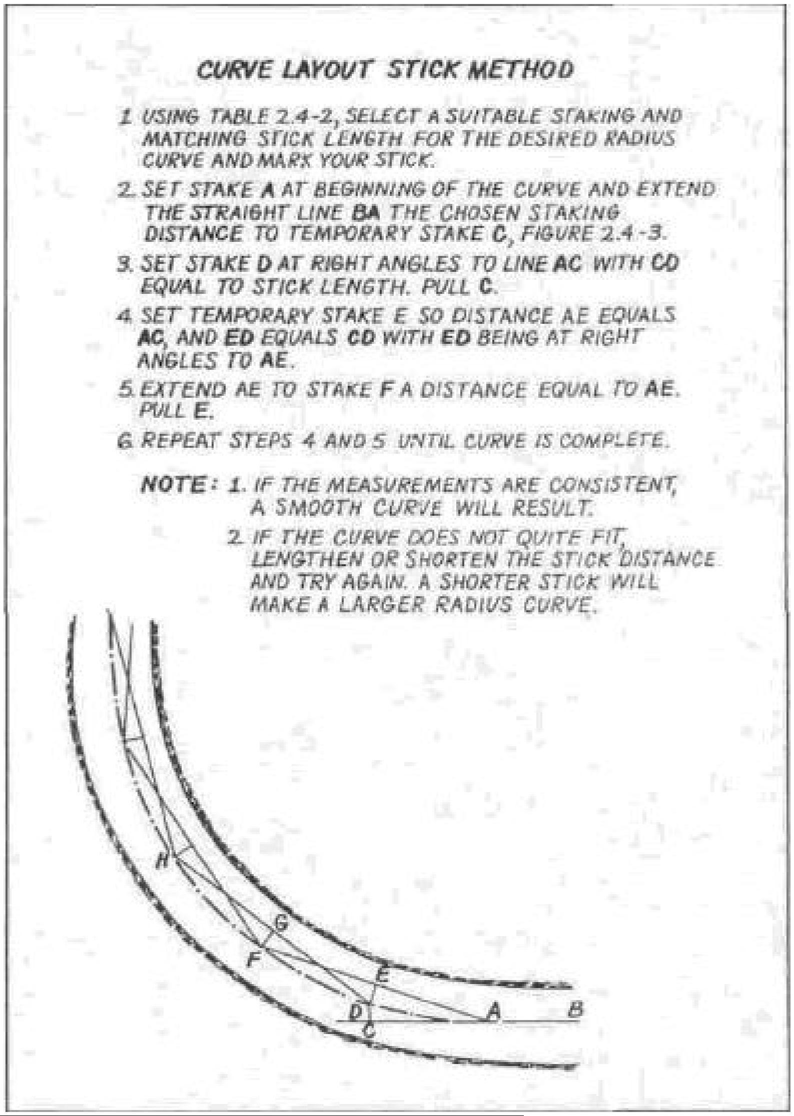
Where two control points cannot be reached by running maximum grade in a single direction, switchbacks are required. They are placed at the point where a grade reverses direction on a slope. Find the location for a switchback by running the greatest allowable grade downhill from the higher control to a location suitable for the turn.

Good switchback sites are areas with little side slope where the loop may be constructed with the least excavation. Look on low gradient benches or along broad, flat ridges for suitable sites.

Once the switchback has been located, you reverse the course of the tagline and continue downhill to see if additional turns are needed. Maximum grade is maintained until all switchbacks are located. Some adjusment can take place after one is assured of reaching the two control points.

Switchbacks usually require much earth movement. For this reason a comparison should be made between crossing controls and the added work to install a switchback.

Figure D-1

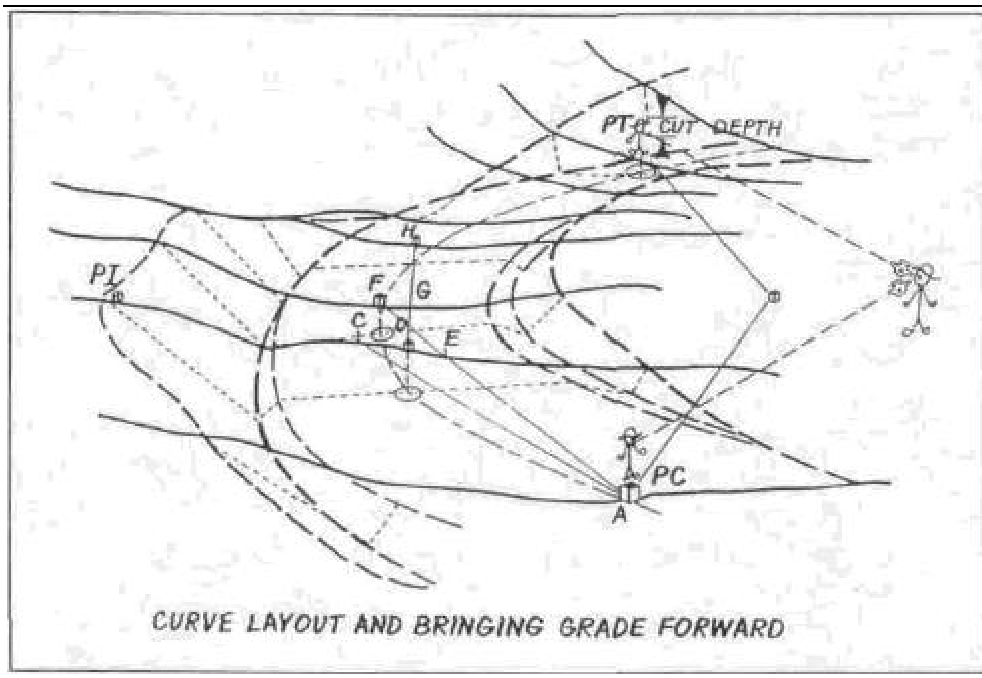


CURVE LAYOUT STICK METHOD

1. USING TABLE 2.4-2, SELECT A SUITABLE STAKING AND MATCHING STICK LENGTH FOR THE DESIRED RADIUS CURVE AND MARK YOUR STICK.
2. SET STAKE **A** AT BEGINNING OF THE CURVE AND EXTEND THE STRAIGHT LINE **BA** THE CHOSEN STAKING DISTANCE TO TEMPORARY STAKE **C**, FIGURE 2.4-3.
3. SET STAKE **D** AT RIGHT ANGLES TO LINE **AC** WITH **CD** EQUAL TO STICK LENGTH. PULL **C**.
4. SET TEMPORARY STAKE E SO DISTANCE AE EQUALS **AC**, AND **ED** EQUALS **CD** WITH **ED** BEING AT RIGHT ANGLES TO **AE**.
5. EXTEND AE TO STAKE **F** A DISTANCE EQUAL TO **AE**. PULL **E**.
6. REPEAT STEPS 4 AND 5 UNTIL CURVE IS COMPLETE.

NOTE: 1. IF THE MEASUREMENTS ARE CONSISTENT, A SMOOTH CURVE WILL RESULT.

2. IF THE CURVE DOES NOT QUITE FIT, LENGTHEN OR SHORTEN THE STICK DISTANCE AND TRY AGAIN. A SHORTER STICK WILL MAKE A LARGER RADIUS CURVE.



CURVE LAYOUT AND BRINGING GRADE FORWARD

*Figure **D-2.***

Reduce the grade of the straight stretches into and out of the switchback. This will help maintain the grade through the curve. The curve itself is set at not more than 8 percent grade, and preferably much less.

There should be no more excavation of the hillslope than that needed to form fill along the lower side of the switchback. This is accomplished by offsetting the center of the curve until about half the curve is excavated.

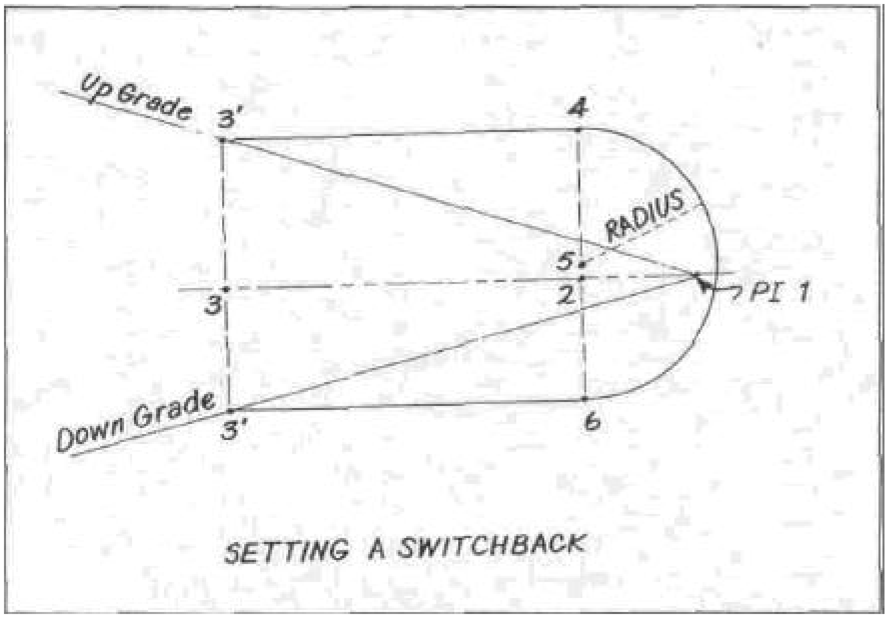
To construct a switchback, do the following:

Figure D-3.

1. Stake intersection of the two grade lines, stake 1, Figure D-3.

2. Bisect the intersection angle, and set stake 2 on the line a curve radius distance from the point of intersection (PI).

3. Along the line bisecting the angle, place a stake 3 on its path where a right angle line equal to the curve diameter just touches the two grade lines. Set stakes 3'.



4. From the upper tagline,
run a new grade line back to the curve from stake 3 feet at approximately 2 percent less than the tagline grade. Where this new line reaches the extension of a right angle line from stake 2, set a new stake 4.

5. Measure the radius distance along the right angle line from stake 4 and place a new stake 5 for the center of the curve.

6. Mark out a curve using the center stake 5 until the extended right angle line from stake 2 is again reached. Set a stake 6.

7. From stake 7 run a grade line that will reach stake 3 feet along the lower side of the curve.

8. Note: Distances measured are horizontal (correct for slope. Table 11 (Chapter III). Constructing a right angle. Figure D-4. Bisecting an angle, Figure D-5.

Figure D-4.

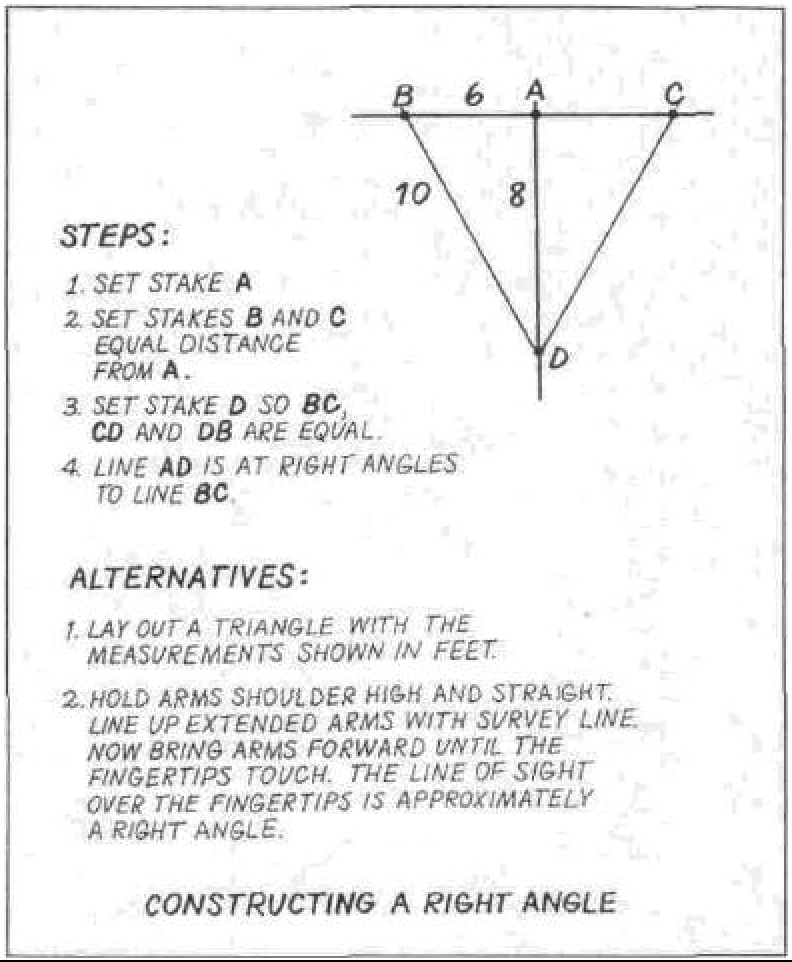
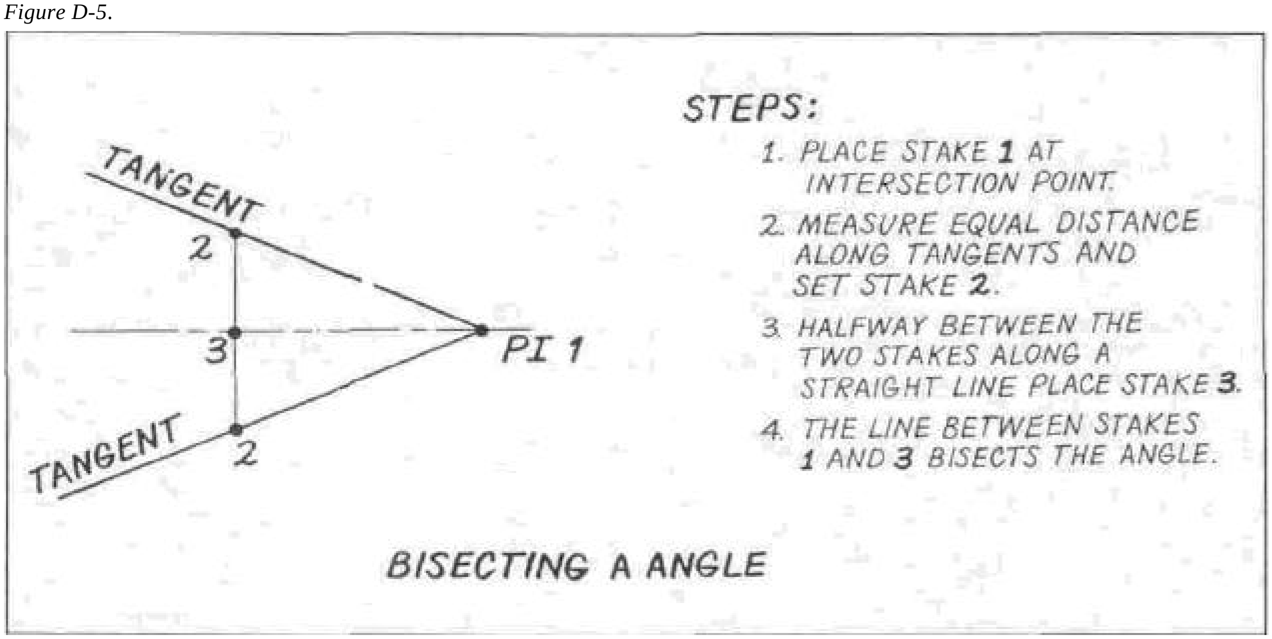


Figure D-5.



APPENDIX E: ESTIMATING CULVERT LENGTHS

Determining needed culvert lengths

The following simplified procedure 1 can be used to determine culvert lengths needed for installation of a new stream crossing or a ditch relief drain. Refer to the following diagram for specific locations and distances described in the step-by-step procedure. A complete example follows the step-by-step instructions.

STEP DO THIS...

1. **Estimate the depth of the fill (F) at the running surface on the inside of the road above the culvert inlet (point "a").**
2. **Additional width (C) due to fill is then estimated as 1.5 times the fill depth (F) (that is, all fill slopes are assumed to be 1.5:1 in steepness)**
3. **Add half the road width (½ W) and the fill width (C). Measure this distance horizontally upstream from the center line of the road and place stake at location A. The horizontal distance must be converted to slope distance before you can tape it off on the ground. Converting horizontal distance to slope distance (on-the-ground distance) is simple using the following chart.**
4. **Repeat steps 1 through 3 for the culvert outlet side of the crossing and place stake at location B.**
5. **Measure the slope length between stakes A and B. This measurement, plus two to four extra feet, is the length of culvert needed for the installation. The extra several feet are added to extend the inlet and outlet beyond the edge of the fill.**

1 Method for estimating required culvert lengths described in USDA (1981).

Slope correction factors to convert horizontal distance to slope distance			
Hillslope or stream channel gradient (%)	Correction factor (multiplier)	Hillslope or stream channel gradient (%)	Correction factor (multiplier)
10	1.00[1]	45	1.10
15	1.01	50	1.12
20	1.02	55	1.14
25	1.03	60	1.17
30	1.04	65	1.19
35	1.06	70	1.22
40	1.08	75	1.25

1 for a slope of 10% or less, no correction factor is needed.

For example: 44 feet horizontal distance equals 52.4 feet slope distance on a 65% slope.

horizontal distance **X** **correction factor** **=** **Slope distance**

(44ft) **X** **(1.19)** **=** **52.4ft**

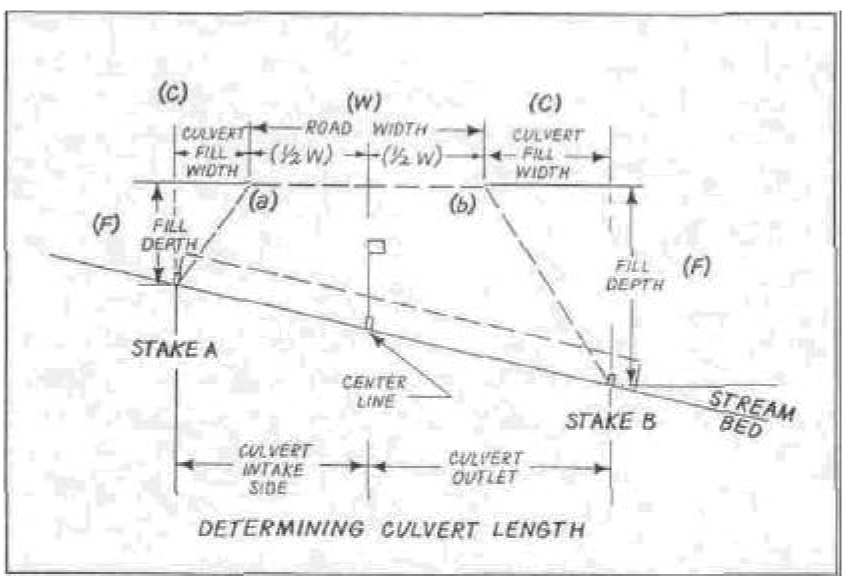


Figure E-l.

Example problem: ***What culvert length is needed for a 14 foot wide road crossing a stream with a 55% gradient. The estimated inside/ill depth, above the cmp inlet, will be 6 feet and the fill depth above the outlet will be 13 feet.***

Step 1: Estimated depth of fill (F) at culvert inlet = 6 feet

Step 2: C = 1.5 x 6 = 9 feet

Step 3: Want 14 foot wide road (W), so ^ x 14 = 7 feet

Stake A (the location of the culvert inlet) should be placed on the ground a distance of (9+7) = 16 horizontal feet up the stream channel from the flagged centerline of the road. According to the correction table, 16 feet horizontally on a 55% slope is **18.2 feet** slope distance (16' x 1.14 = 18.2'). ***Place the inlet stake** (A) **18.2 feet up the channel from the centerline of the road.***

Step 4: Estimated depth of fill (F) at culvert outlet =13 feet

Step 5: C = 1.5x13 = 20 feet

Step 6: Want 14 foot wide road (W), so ½ x 14 = 7 feet

Stake B (the location of the culvert outlet) should be placed on the ground a distance of (13 + 20) = 33 horizontal feet down the stream channel from the flagged centerline of the road. According to the correction table, 33 feet horizontally on a 55% slope is **37.6 feet** slope distance (33' x 1.14 = 37.6'). ***Place the outlet stake** (B) **37.6 feet down the channel from the centerline of the road.***

Step 7: Length of culvert needed = 18.2' + 37.6' = 55.8' or about **56** feet. Approximately two to four feet should be added to this length to make sure the culvert inlet and outlet extend sufficiently beyond the base of the fill.

Final culvert length to be ordered and delivered to the site = 56' + 4' = 60 feet